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AUTOMATED EARLY FATIGUE DAMAGE SENSING SYSTEM

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An automated fatigue damage sensing system was developed to detect the presence of cracks as small as 0.050 in. propagating on full scale aerospace structures undergoing fatigue tests. The detection system uses acoustic emission technology with computerized graphic displays to present the data. The graphic displays are generated from user digitized drawings of the part under test. Fatigue damage data is automatically overlayed on the picture of the part under test.

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SUMMARY

The overall program objective was to develop a user-friendly system which is capable of detecting the initiation and propagation of 0.050-in. cracks under actual fatigue test conditions.

The approach taken to accomplish this objective involved an evaluation of candidate techniques through feasibility studies, which eventually selected Acoustic Emission (AE) as the most appropriate technique.

The approach then provided system development tasking which included an iterative process for preliminary system evaluation, followed by a final experimental demonstration to verify that the objectives had successfully been met.

As a result of this program, a computer-based AE system was developed which incorporated the concepts of graphic display of the test specimen and sensors along with data plotting to produce a user-friendly system that is capable of detecting and locating 0.050-in. cracks under fatigue test conditions.

PREFACE

This technical report documents the development work performed under Contract F33615-83-C-3225, "Automated Early Fatigue Damage Sensing System." The program was conducted at the Grumman Corporation's facilities in Bethpage, New York for the Air Force Wright Aeronautical Laboratories, Flight Dynamics Laboratory, Wright Patterson Air Force Base, Ohio 45433-6553, represented by Mr Joseph Pokorski. This effort covered the period from December 1983 to September 1987, including a one-year extension.

The program was conducted by Mr Alan Hencken and Mr Michael Horn, Project Engineers, and managed from Grumman's Advanced Development Laboratory by Mr Richard Chance.

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1 - INTRODUCTION

1.1 BACKGROUND

Structural fatigue testing plays a vital role in assuring the long-term integrity of aerospace vehicles and components. However, substantial uncertainty involving large-scale complex structural tests does exist due to their inherent "one shot" nature. Crack propagation not revealed by a catastrophic failure during a single test can cause structural problems later in production aircraft. Grumman Aerospace recognition of the need for a reliable and practical technique to detect these warning cracks is evidenced by the Company's commitment to R&D efforts in this area for the past several years.

A reliable/practical technique must take into consideration flaw detection sensitivity and peculiar constraints of structural test conditions. Modern structural designs utilize high-strength materials in highly loaded areas where critical flaw sizes in the 0.050-in. range are common and must be detected prior to reaching that level. Complex structural tests typically involve critical structure weakened by fastener holes and concealed by closure skins. Load conditions are usually highly variable (spectrum) and result in severe induced vibrations and "oil canning" in the structure. In addition, the fixtures, loading devices, and cables at a typical structural test site frequently make direct access to the structure impractical. The selected crack detection technique(s) must consider all these factors as well as be tolerant of extreme ambient environment conditions, and it must be usable by technicians without extensive training.

1.2 PURPOSE/OBJECTIVE

The overall objective of this program was to develop a reliable non-destructive testing system for the detection of initiating cracks generated during structural fatigue testing. The goals were to (1) detect cracks as small as 0.050 in. in complex structures and (2) develop a detection system that could be operated by technician-level personnel typically assigned to structural test areas.

2 - FEASIBILITY STUDIES

2.1 TECHNICAL APPROACH

2.1.1 Technical Discussion

All available nondestructive techniques were considered in the initial effort. Preliminary assessments of candidate crack detection technologies conducted by Grumman prior to this contract award were reexamined in light of the most recent advancements and found to be unchanged. Subsequently, the three most viable techniques were further evaluated experimentally to identify the most feasible technique.

2.1.2 Review of Technologies

A thorough literature search of recent developments was conducted utilizing the N.T.I.S. and Compendex Systems, the key search words being Fatigue Test, Fatigue Damage, Crack Initiation, and Nondestructive Testing. A total of 575 abstracts were provided and reviewed. In addition, the transactions of the research-oriented "Quantitative Nondestructive Evaluation (NDE) Conference" held in August 1983 were reviewed. Personal contacts were also made with major NDE Research Laboratories to acquire the most recent advancements. The result of these reviews was a reconfirmation that the three most promising techniques were optical correlation, ultrasonics, and acoustic emission. Table 1 summarizes the rationale used in selecting these techniques.

2.2 ULTRASONICS

2.2.1 System Description

The system used for evaluating the ultrasonic array technique was assembled using available in-house equipment. This included a high-resolution flaw detector transducer array, multiplexor, and signal analyzer. The ultrasonic instrument includes, as a unit, the pulser/clock, amplifier, and display. The Branson 303B was selected for this role because of its high resolution display, reliability, and portability to test areas.

TABLE 1 COMPARISON OF CANDIDATE TECHNOLOGIES VS FATIGUE TEST CONSTRAINTS

√ – CAPABLE
X – NOT CAPABLE
? – UNKNOWN CAPABILITY

CANDIDATE TECHNOLOGIES	FACTORS AFFECTING PERFORMANCE									
	MECHANICAL NOISE DISCRIMINATION	ELECTRICAL NOISE DISCRIMINATION	STACKED/CLOSED SKIN INACCESSIBILITY	TEST FIXTURE/STRAIN GAUGE INACCESSIBILITY	EXTREME ENVIRON. CONDITIONS	PHYSICAL JARRING	CRACK DETECTION SENSITIVITY	CRACK PROPOGATION RATE	LARGE AREA COVERAGE	FALSE CALL IMMUNITY
ACOUSTIC EMISSION	√	√	√	√	√	√	√	√	√	√
ULTRASONICS	√	√	?	√	√	√	X	√	X	?
FOIL FATIGUE SENSORS	?	√	X	X	√	√	?	?	?	?
EXOELECTRON EMISSION	√	?	X	X	√	?	√	?	?	?
RADIOGRAPHY	√	√	X	?	√	√	X	?	?	?
THERMAL SCANNING	√	√	X	X	X	√	?	?	√	?
EDDY CURRENT	√	√	X	X	√	√	√	√	X	?
OPTICAL CORRELATION	X	√	√	√	√	√	X	?	?	?
MICROWAVE	√	√	X	X	X	X	√	√	X	?
RESONANCE	√	√	X	X	√	√	√	√	?	?
SURFACE POTENTIAL	√	?	X	X	√	√	?	?	?	?
STRAIN ENERGY	?	√	X	X	√	√	?	?	?	?
MAGNETIC PERTURBATION	√	?	X	X	√	√	?	?	X	?
STRAIN GAUGE	?	√	X	X	√	√	?	?	?	X
ELLIPSOMETRY	√	√	X	X	X	X	X	?	X	?

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The second part of the system is the ultrasonic arrays. These contain shear wave 45° and 70° angle beam piezoelectric sensors built into a common housing. They are fabricated in arrays of four sensors as shown in Fig. 1. The arrays were specially built for Grumman by Ultran Inc.

The third part of the system, the multiplexor unit, enables the excitation of the sensors and separate viewing of each one on the single-channel Branson 303B instrument. This unit is placed in-line between the array output and 303B amplifiers. The Aerotech 16-channel multiplexor was used for this task, and is capable of either manual or automatic scanning of the array outputs.

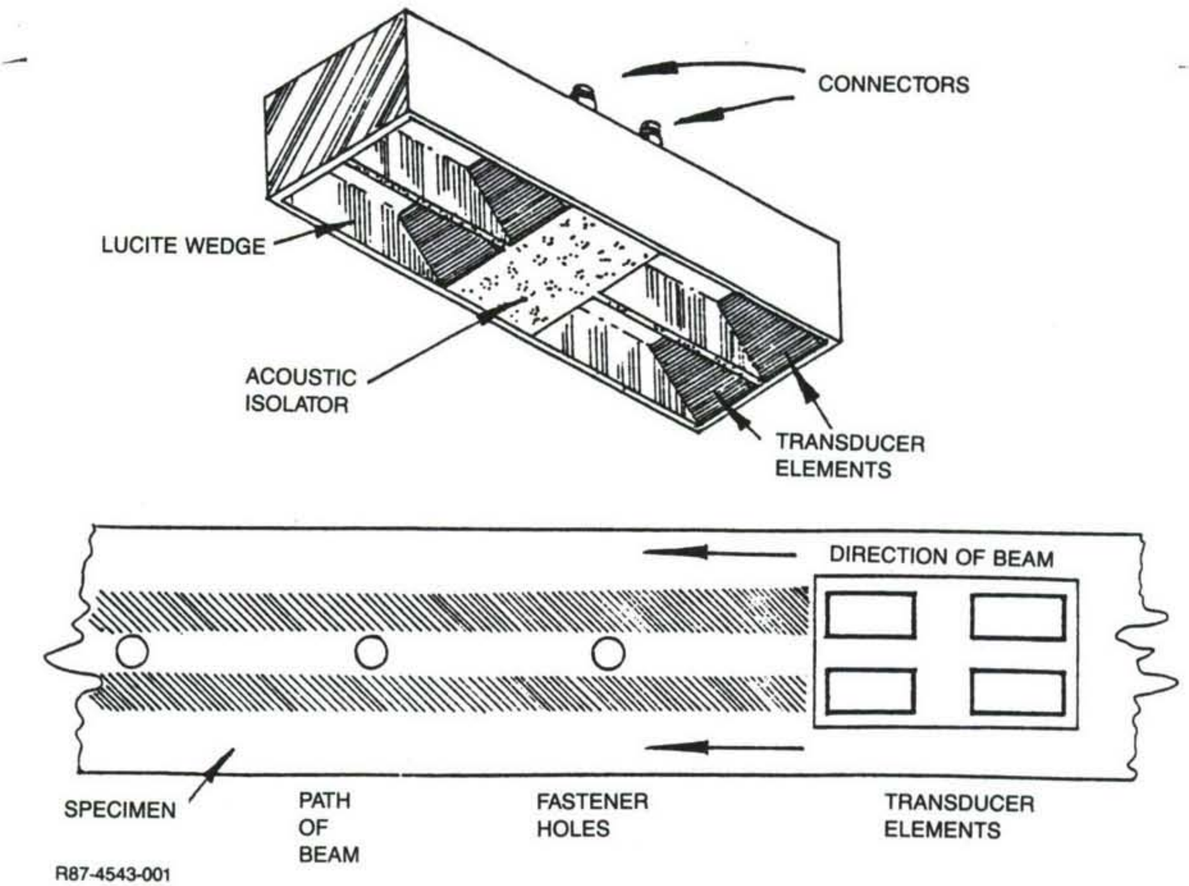

Fig. 1 Ultrasonic Array

To evaluate all of these channels of data from the test would be difficult without the storage capabilities of a computer. A Hewlett-Packard 2048 graphics terminal with megabyte memory storage was included to complete the recording and updating of the data from the arrays during dynamic fatigue testing.

2.2.2 System Operation

The system assembled to evaluate ultrasonic arrays is based upon conventional pulse-echo ultrasonic technology. This method of nondestructive testing is very capable of detecting small (less than 0.050 in.) surface and subsurface flaws and cracks. It can also provide sufficient data to allow crack location.

The basis of pulse-echo ultrasonics is the piezoelectric crystal transducer, which can transmit and/or receive ultrasonic energy in materials. The ultrasonic beam, like a searchlight, is scanned through the material under test

until it illuminates the flaw or crack with sound energy. The beam returns to the transducer with an energy commensurate with the size, distance, and orientation of the crack to the transducer. Certain factors such as scatter, beam spread, and dispersion reduce the sensitivity of the illuminating beam. By placing the transducers in arrays, a wide field of coverage can be obtained without scanning (see Fig. 1). The paths of the beam can be staggered to assure maximum coverage. Cracks occurring near the surface of any fastener holes in the area of coverage on the specimen should be detected by one of the transducers in the array. If the crack is oriented unfavorably to the array, however, the illuminating beam will bounce off at an angle and not return directly to the array. The beam can only return in this case by a roundabout route of fortunate bounces off the edges and surfaces of the specimen. This roundabout trip can provide the basis of an indirect method of crack detection for cracks not favorably oriented to the array.

2.2.3 Testing Approach

The evaluation of the ultrasonic technique was planned to proceed in three steps: (1) sensitivity evaluation, (2) signal analysis optimization/evaluation, and (3) application to dynamic fatigue test specimens. In actuality, the last two steps were not completed due to the poor results obtained during the sensitivity evaluations.

2.2.4 Test Results

An ultrasonic array was coupled to a specimen using glycerine. It was manually manipulated to pick up an echo from a 0.050-in. crack propagating from the first hole in the specimen. At a distance of 1 in. from the edge of the hole, the array readily produced a 50% screen height (see Fig. 2A). Range select was set at 5 in. with no damping or reject in use. As the array was pulled back from the cracked hole, the signal accordingly diminished in screen height and shifted to the right, along the baseline. However, the signal from the hole did not drop as fast as that of the crack. As the distance to the array increased, the signal to crack signal ratio changed; maintaining that the screen height for the crack caused the hole baseline signal to rise above it (see Fig. 2B). At about 3 in., the array-to-hole crack signal became lost in the noise of the baseline (see Fig. 2C).

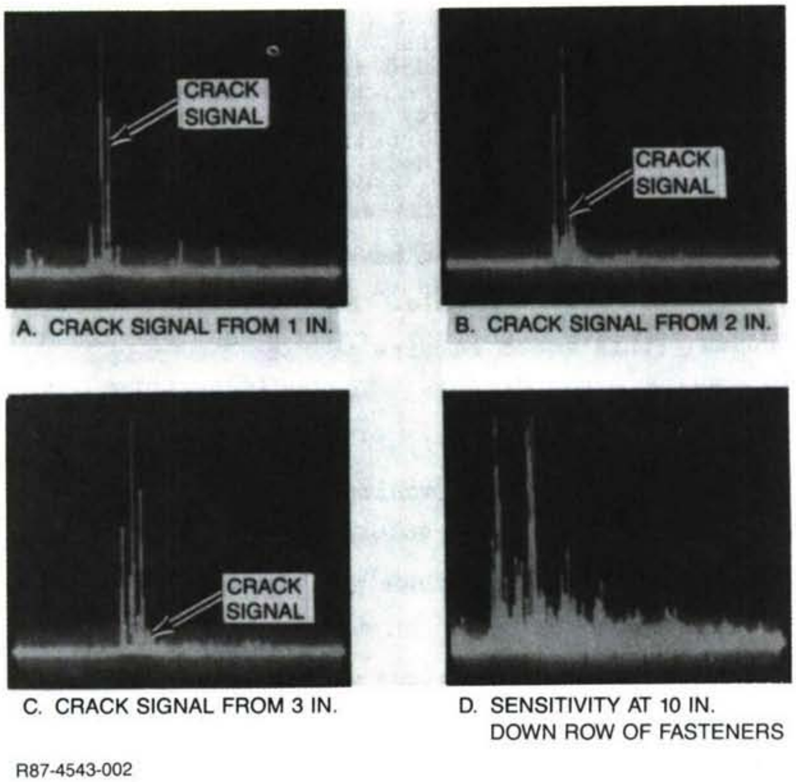

Fig. 2 Ultrasonic System Sensitivity

The array was then aimed down the row of fastener holes to observe the effects of the near field when the last hole was resolved to 30% screen height. For this part of the experiment 96 dB was used and the range was set at 50 in. A considerable amount of near-hole data was lost when trying to resolve the distant fastener holes (see Fig. 2D). No crack signals were obtained for the distant holes when gain settings were optimized for the near holes.

The effect on the ultrasonics technique by a non-optimum (but realistic) crack orientation was conducted to further evaluate its sensitivity. The system was set up on a specimen with a 0.500-in. long crack in the last fastener hole. The ultrasonic response to this crack was greater than the response from the fastener hole. The crack could be detected up to 10 in. away when the beam was aimed down the row of holes on the cracked side. When the array was aimed down the same row of holes on the non-cracked side to simulate a worst-case crack orientation, detectable wave train signals could be noted. That is to say, the response from the holes dropped off normally as though no cracks existed in the specimen. As far down the baseline as the end of the

specimen, there were no signals evident which could be attributed to the 0.500-in. crack.

2.2.5 Conclusions

Cracks in the size range of 0.050 in. can be detected by pulse-echo techniques provided they are in close proximity to the ultrasonic transducer, and not near a large reflector such as a fastener hole. The row of fastener holes interacting with the spreading beam of the sensor created a large noise source which may have masked the crack signal. The array did not have the sensitivity required to detect a crack at practical distances from the hole. At least one array would be needed for every two fastener holes. This would require perhaps hundreds of arrays all over the fatigue test structure.

When the ultrasonic array was monitoring a nearby crack, it was very insensitive to noise. When monitoring a crack beyond 3 in., however, the noise discrimination became very poor and resulted in failure to detect the crack.

Other limitations to the technique were observed during these evaluations. During the tests, it was noted that bending the specimen very slightly caused the baseline of the display to shift in amplitude and time. It was assumed that a fatigue test would also cause similar changes in response. Baseline and flaw signal shifts also occurred when the array experienced angular displacement. During a fatigue test, the array would have to be fastened to the specimen by means that would isolate it from this problem (see the results of coupling problems in the section on AE).

The ultrasonic arrays can detect and locate a 0.050-in. long crack at close range, under ideal conditions. Crack distance and orientation are crucial factors for detection. Also, the large noise source of the hole creates a difficult environment in which to detect cracks when the hole is more than a few inches away from the array.

The results of the test reported here indicate that further evaluation was not warranted due to the great level of effort required to develop this technique to a practical and sensitive level of performance.

2.3 ELECTRO-OPTICAL SENSORS

2.3.1 System Description

Fatigue tests were monitored with an Electro-Optical (E-O) sensor system specifically designed and built by R.A.D. Inc. The E-O sensor amplified outputs were transferred to a Physical Acoustics Corp. Model 3400 linear location system to generate linear locations from crack initiation and propagation signals. A Nicolet Scientific Corp. Model 446A Mini-Ubiquitous Spectrum Analyzer was used to perform frequency analysis of the amplified signals from the E-O sensors.

2.3.2 System Operation

The E-O probe and amplification system is sensitive to flexural wave frequencies to 1 MHz with a gain of 80 dB. The probe is affixed to the surface of the test piece for the purpose of monitoring flexural displacements which result from crack propagation.

In order to acquire crack initiation data from the subject surface, a beam of collimated infrared light is transmitted across a gap in the transducer to a mirrored surface and reflected back to a detector array. The gap provides a reference distance over which the mirrored surface can flex, or angulate, relative to the emitter and detector array. Light falling on the detector array illuminates individual elements of the array with different intensity levels depending on the angular displacement of the mirror. The signals generated from the detector array are amplified and transferred to a linear location system. The Physical Acoustics Model 3400 linear location system receives the amplified signals from two E-O probes and creates delta time information which is processed for source location calculations and plotted on a CRT display.

The amplified signals from the E-O probe can also be transferred to the Nicolet Scientific Corp. Model 446A Mini-Ubiquitous Spectrum Analyzer which operates in a peak continuous mode (the maximum spectral output at the given frequency is retained). Spectral averages of 512 samples are obtained in the 512-sample summation mode.

This processing provides better definition of the high-frequency signals normally associated with a crack and the lower-frequency signals associated with material fatigue test equipment.

2.3.3 Test Setup

Since this technique relies on the detection of propagating cracks, its evaluation must be conducted under dynamic testing conditions. Therefore, fatigue tests were conducted utilizing an M.T.S. servo-hydraulic fatigue test machine. The specimens were placed in the machine and fatigued with constant-amplitude tension-tension loading conditions.

The specimens monitored were the simple dog-bone type with one hole as shown in Fig. 3. The E-O sensors were placed at the locations shown for the AE transducers and mounted onto the test specimens with an alpha-cyano acrylic quicksetting adhesive. These tests were conducted concurrently with the AE technique evaluation for cost effectivity, and to permit the more established AE to be used as a crack initiation/propagation indicator.

2.3.4 Test Results

The above-mentioned technique was evaluated in two stages utilizing simple, one-hole dog-bone specimens. In the first stage, aluminum specimens were monitored simultaneously with tuned 300-kHz AE sensors, as well as E-O sensors, hooked into their respective linear location systems. The tuned 300-kHz AE sensors were hooked into the Grumman AE monitoring equipment and the E-O sensors were hooked in the P.A.C Model 3400 linear location equipment. The two systems were calibrated by tapping on the hole in the test specimen, thereby causing the locations to appear on their respective histograms.

Three specimens were cycled at a load of 29 ksi and cycle rate of 3 cycles/sec. In all three cases, the E-O sensors did not generate any location data for the duration of the fatigue tests, which were taken to failure. For Specimen 2, Fig. 4 and 5 demonstrate the dramatic difference in response from a 0.450-in. crack between the piezoelectric sensors and the E-O sensors. The AE sensors generated hundreds of source locations from this crack while, at the same time, the E-O sensors generated no source locations at all.

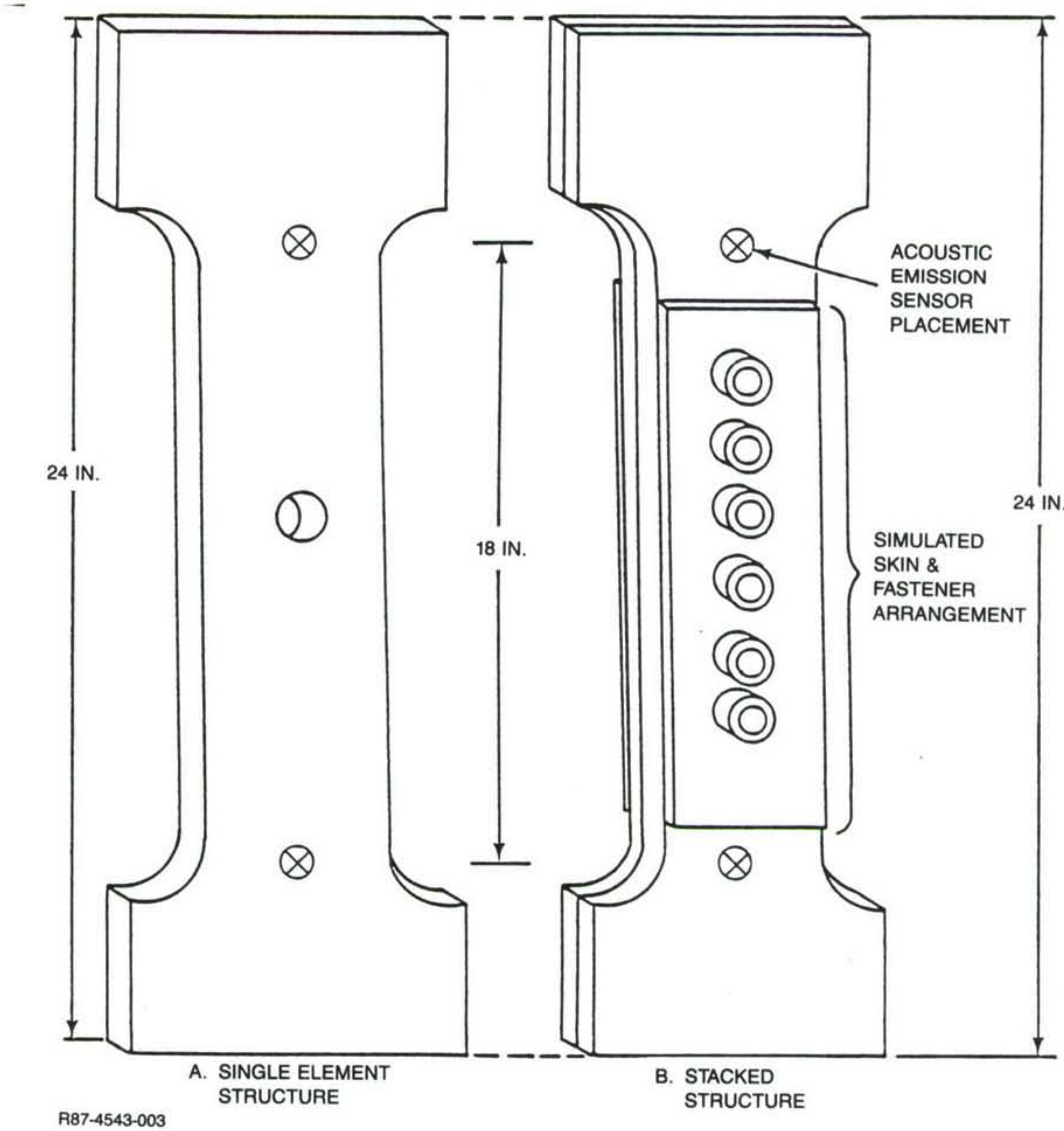

Fig. 3 Phase I Fatigue Test Specimens

The E-O sensors were returned to the manufacturer for recalibration and improvements in an attempt to increase their sensitivity. After recalibration and improvements were made, the sensors were installed on Specimen 12, a simple dog-bone specimen constructed of titanium. AE monitoring techniques detected crack initiation in the specimen at cycle 35,050. The E-O sensors were installed at that point to prove its crack detection capabilities. The sensors were tied into the Nicolet-Scientific Corp. Model 445A Mini Ubiquitous Spectrum Analyzer for a complete frequency analysis over a wide range (1 Hz to 100 kHz) of frequencies.

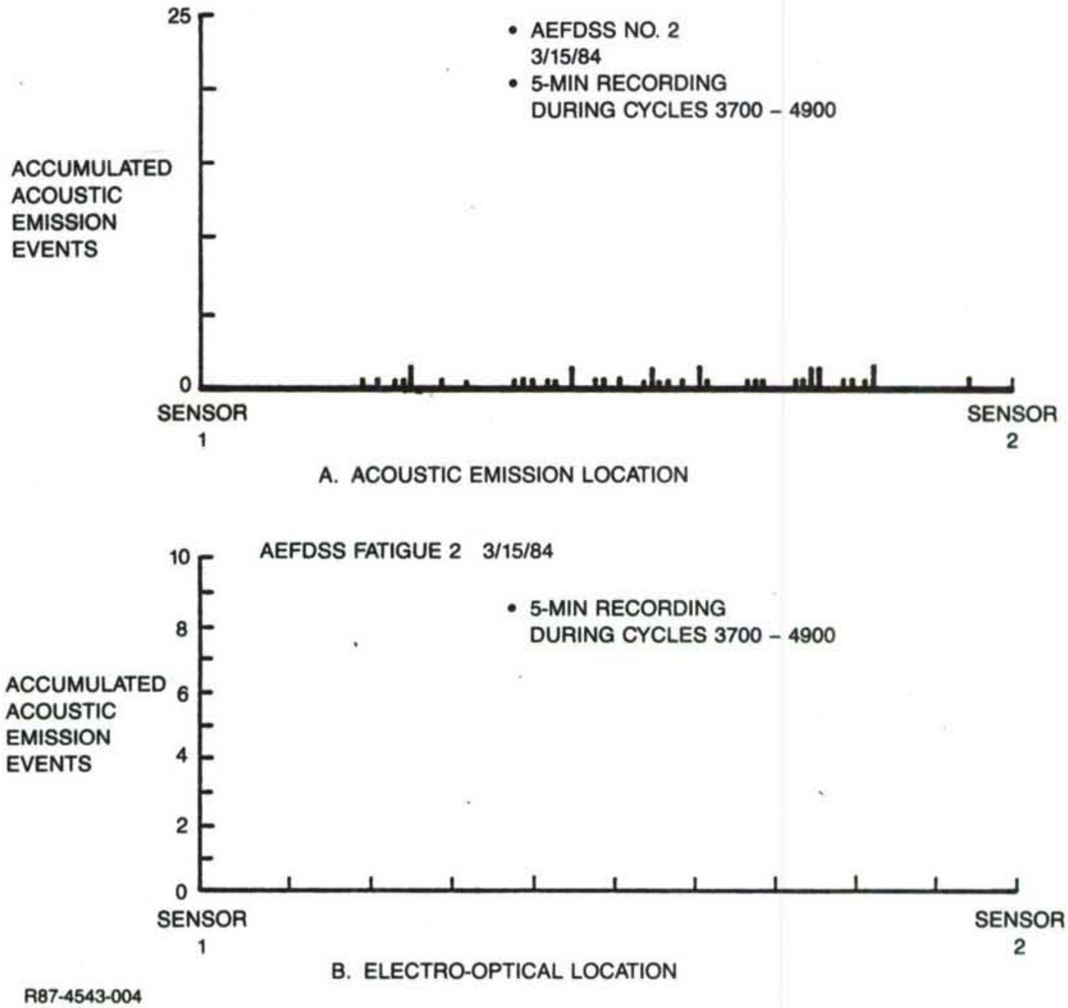

Fig. 4 Acoustic Emission Vs Electro-Optics: No Crack

Figure 6 shows the data obtained from Specimen 12. The data are plotted as frequency vs amplitude in dB. A review of the data shows that there are two trends at two widely separated frequencies. One discernable peak appears at approximately 67 kHz. According to the frequency plots, a peak rises slightly as the number of cycles increase from 36,500 to 39,440 cycles. Also, at about 46 kHz, a peak rises over the same cycle range. Across the spectrum, at 800 Hz, a very prominent peak can be seen to rise at 37,390 cycles from its baseline only to drop down relative to it. Among other significant peaks, the most prominent appears at 600 Hz, increasing for 890 cycles and then almost disappearing 2000 cycles later.

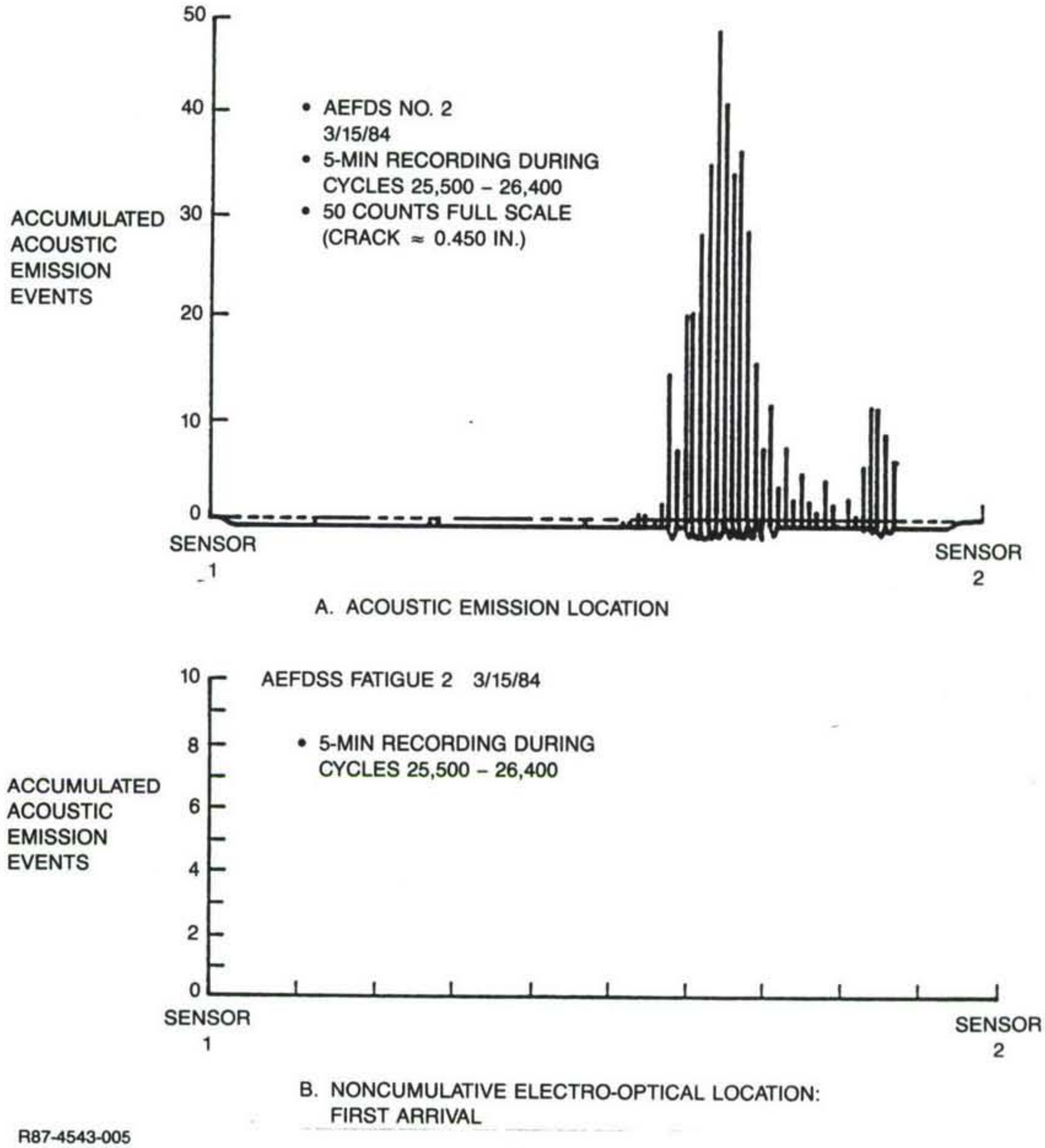

Fig. 5 Acoustic Emission Vs Electro-Optics: 0.450 In.-long Crack

2 .3.5 Conclusions

The data were determined to be inconclusive with no firm demonstration that the E-O technique is capable of reliably detecting fatigue crack propagation. Several peaks were observed that might be indicative of a crack, but the technique is unreliable without a theoretical understanding to guide the selection of the proper frequencies to analyze.

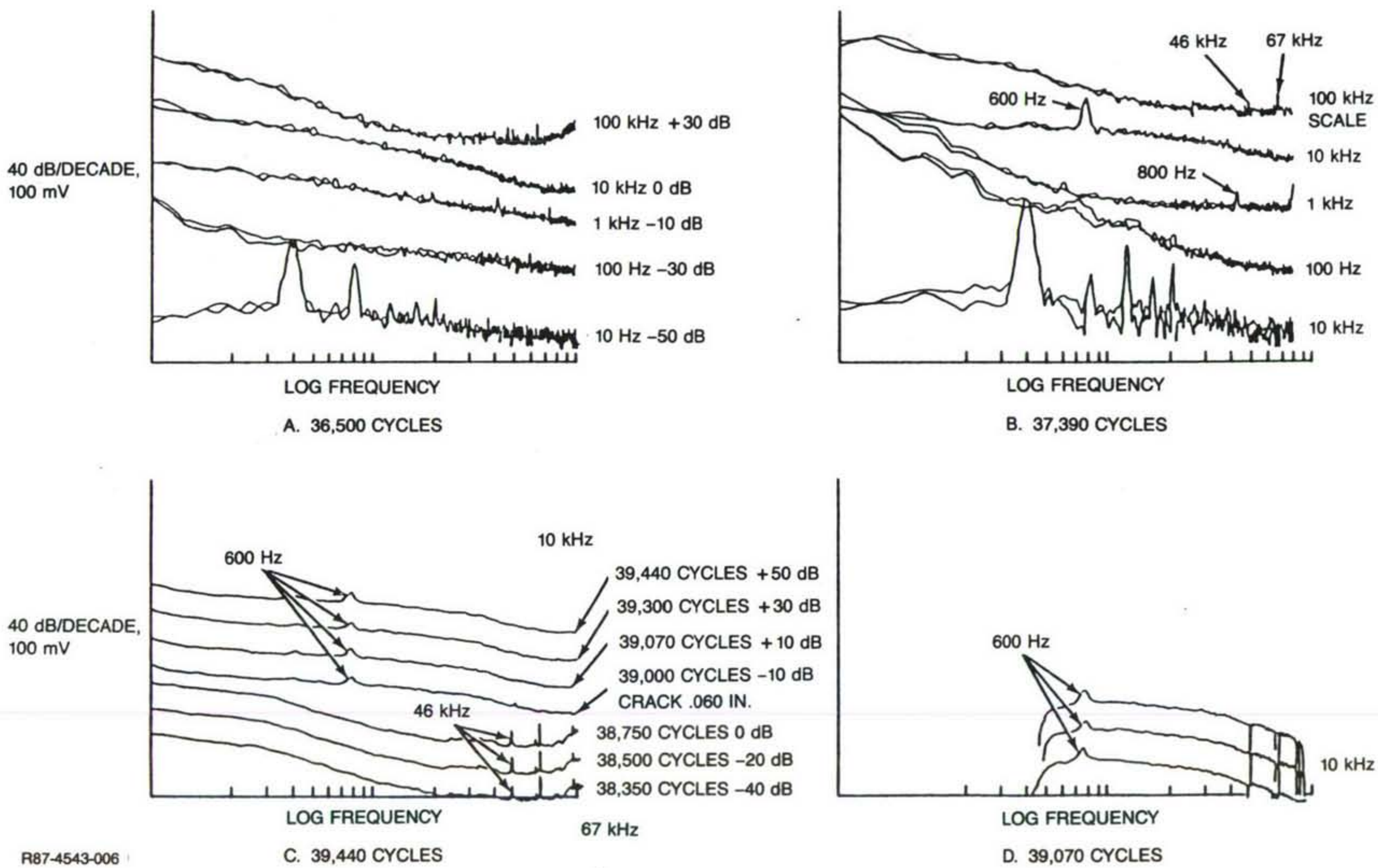

Fig. 6 Frequency Data from Electro-Optical System

2.4 ACOUSTIC EMISSION

2.4.1 System Description

Fatigue tests were monitored utilizing a Grumman-developed four-channel AE monitoring system and a Physical Acoustics Model 3400 four-channel system. The Grumman system, which has been successfully used on AMAVS, CAST, and many other structural test applications, was used as a baseline to evaluate the Physical Acoustics 3400 system. Both systems were designed to detect AE events in a fatigue noise environment, and to locate crack initiation sites, utilizing waveform conditioning and spatial and waveform noise discrimination techniques. The Physical Acoustics 3400 system represents an updated (more microelectronics) but untested version of the Grumman system.

2.4.2 System Operation

The fatigue tests were monitored at a tuned resonant frequency of 300 kHz to provide good sensitivity for detection of low-amplitude (microvolts) crack signals, while eliminating many of the low-frequency vibration noises of the fatigue test apparatus. The system was operated with a total system gain of 80 dB and event detection threshold of 0.5 volt.

Figure 7 shows the source location format used to record the results of the fatigue tests. The data illustrated are those which would have been obtained from a crack initiating at the hole. Ultrasonic sound-wave energy generated from the crack tip would be detected by Sensor 1 first and, at some delta time (microseconds) later, would be detected by Sensor 2. The time difference of arrival at the sensors is transferred to the microprocessor for source location calculations, and the resultant source location is plotted on the display. The source location data are processed and plotted only if it meets the preset requirements imposed for AE events within the monitoring system's hardware. If more than one event occurs at a particular location, it is additive and appears as a vertical line on the plot. AE event activity from crack initiation and growth appears at a single location as groups of multiple events.

Spatial and waveform discrimination techniques were utilized to prevent extraneous noise sources, generated by the fatigue test apparatus, from

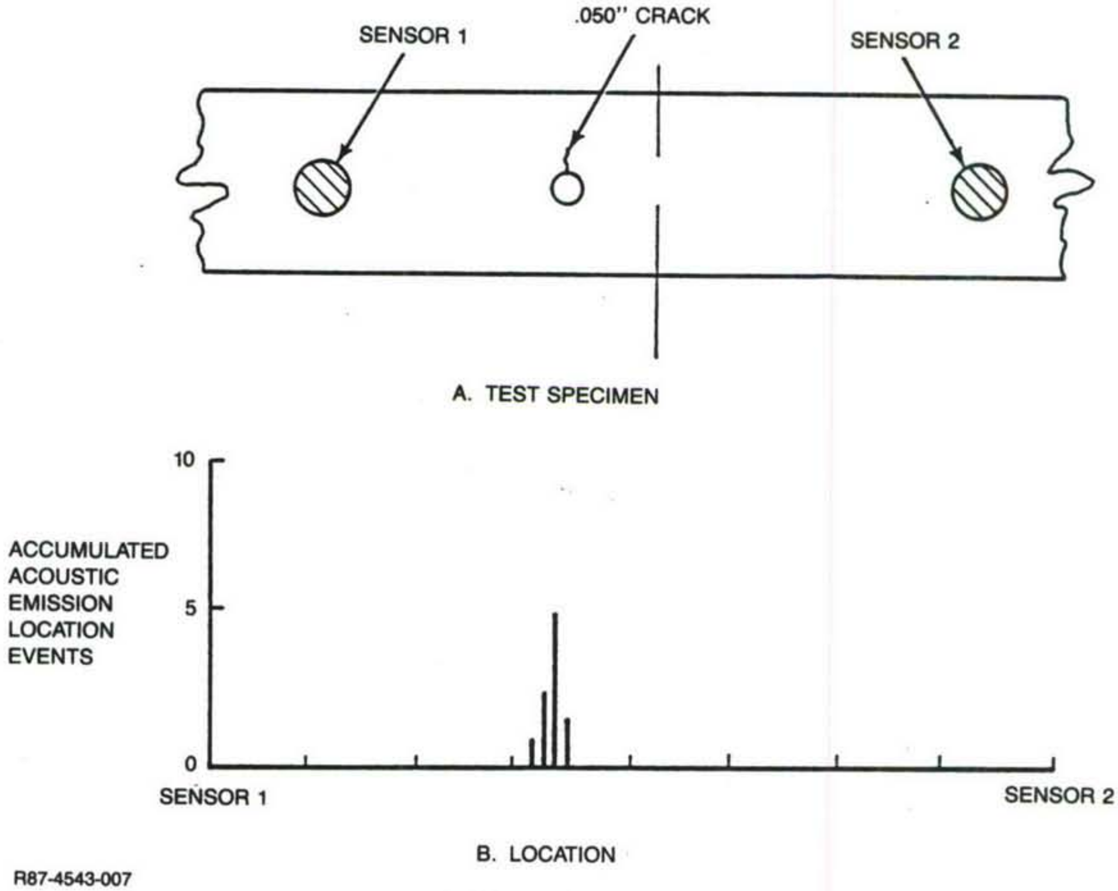

Fig. 7 Source Location Format

interfering with crack initiation and propagation location data. Spatial discrimination techniques eliminate extraneous noise generated from outside the surveillance area by setting a maximum acceptable Δt value. Any Δt value generated which exceeds a preset limit is automatically eliminated and does not appear on the display.

Waveform discrimination eliminates interference from within the surveillance area (fretting surfaces, loose fasteners). This type of interference cannot be eliminated by spatial discrimination because the resultant Δt values fall within the preset Δt limits. Events detected by the system are analyzed for their waveform characteristics. If the waveform of the event does not meet preset requirements, it is rejected. If the event waveform falls within the range of the preset requirements, it will appear on the output display.

2.4.3 Fatigue Test Setup

Fatigue tests were conducted utilizing an M.T.S. servo-hydraulic fatigue test machine. The specimens were placed in the machine and fatigued under constant-amplitude tension-tension loading fatigue conditions. Figure 8 shows the fatigue test setup and monitoring equipment. Two types of test specimens were designed, a simple dog-bone type with one hole, and multiple fastener/ stacked specimens with six holes to simulate comples airframe components. Figure 3 shows the configuration of the specimens and the sensor placements. The simple dog-bone specimens were fabricated out of the three most common structural materials (steel, aluminum, and titanium) and the multiple fastened/stacked specimens were fabricated out of aluminum. The sensors were mounted on the specimens with an alphacyano acrylic quick-setting adhesive.

2.4.4 Test Results

Table 2 shows a summary of the data obtained for each of the 17 test specimens. All of the tests conducted were monitored with respect to reliability, sensitivity, false call vulnerability, and noise discrimination capability of the AE monitoring system. The AE monitoring system reliably detected cracks in each of the test specimens.

The cracks detected varied in size between 0.020 in. and 0.100 in., depending upon how quickly the test was stopped after AE signals were initially detected.

The AE monitoring technique demonstrated very effectively its noise discrimination capabilitites throughout the test program. In all cases, extraneous noise signals from the fatigue test apparatus and the fastened holes were prevented from interfering with crack initiation and propagation data, thereby eliminating false calls.

2.4.4.1 Simple Dog-Bone Specimens

A total of 12 simple dog-bone specimens were tested. Typical data for aluminum Specimens 3, 4, and 5 are shown in Fig. 9, for steel Specimens 7, 8, and 9 in Fig. 10 and for titanium Specimens 10, 11, and 12 in Fig. 11. The noise-free displays shown are indicative of the many recordings taken periodically until AE location events appeared on the screen.

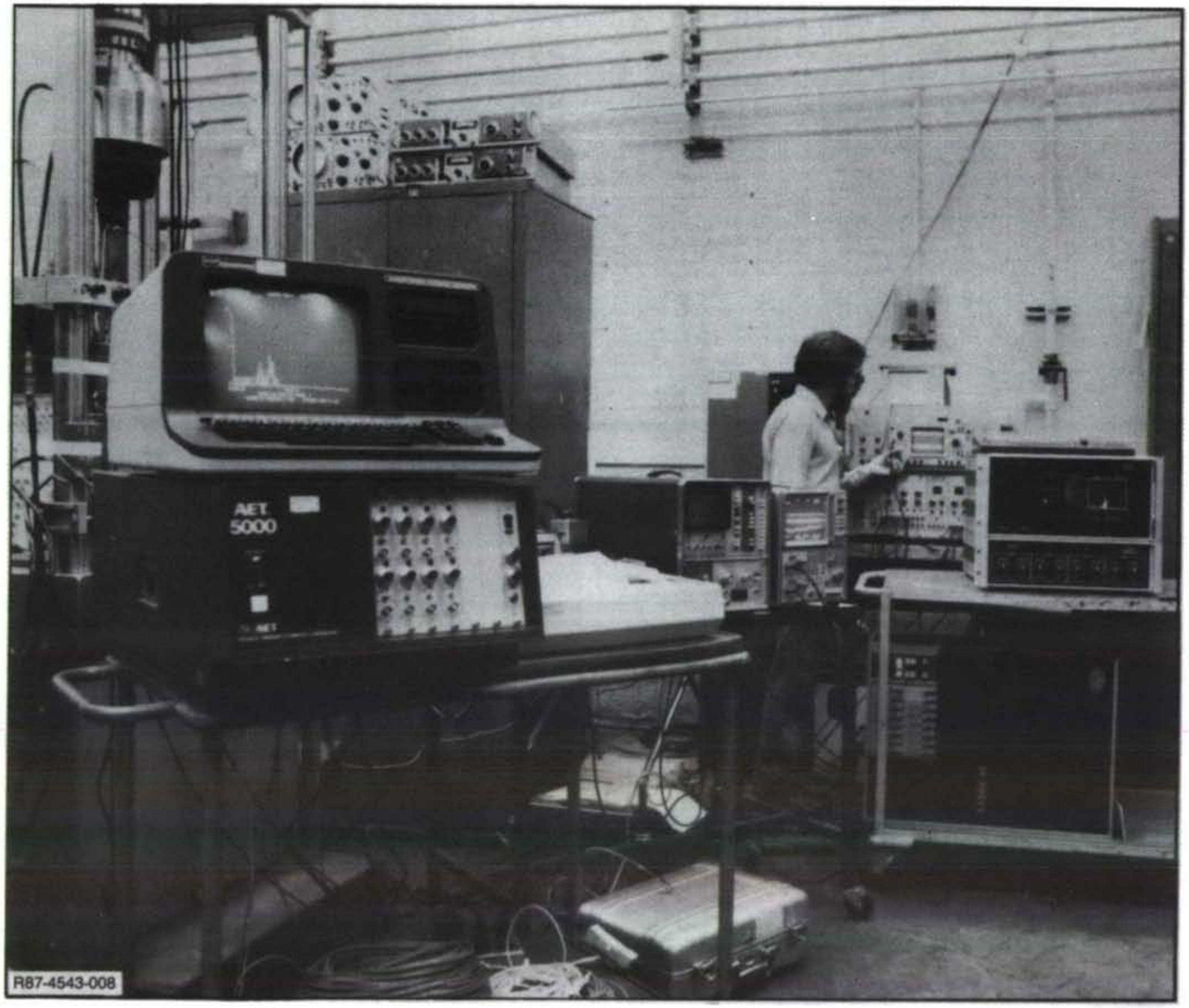

Fig. 8 Prototype AEFDSS System

TABLE 2 SUMMARY OF TEST SPECIMEN DATA

SPECIMEN NO. MATERIAL TYPE	SIZE CRACK DETECTED, IN.	NUMBER OF CYCLES AT DETECTION	TECHNIQUE UTILIZED/RESULTS
1: 7075-T6 ALUMINUM	NONE	NONE	USED FOR HYDRAULIC SYSTEM CALIBRATION
2: ALUMINUM	0.450	26,400	USED FOR COMPARISON OF ACOUSTIC EMISSION & ELECTRO-OPTIC TECHNIQUES
3: ALUMINUM	0.080	84,800	ACOUSTIC EMISSION DETECTED CRACK. TEST STOPPED AT 0.250 IN. SIZE
4: ALUMINUM	0.100	17,150	ACOUSTIC EMISSION DETECTED CRACK.
5: ALUMINUM	0.020	13,430	ACOUSTIC EMISSION DETECTED CRACK. SLOWER CYCLE RATE THAN NO. 3 & 4
6: 4340 STEEL	FAILED	0	FATIGUE MACHINE OPERATOR FAILED SPECIMEN DUE TO ERROR
7: STEEL	TWO CRACKS -0.080 AND 0.040	15,700	ACOUSTIC EMISSION DETECTED CRACKS. SCATTERED LOCATIONS ON DISPLAYS
8: STEEL	0.060	16,700	ACOUSTIC EMISSION DETECTED CRACK
9: STEEL	0.020 TEST STOPPED AT 0.200	0.020 IN. AT 17,300 0.200 IN. AT 19,000	ACOUSTIC EMISSION DETECTED 0.020 IN. CRACK SIGNALS INCREASED AS CRACK GREW
10: 6-6-4 TITANIUM	0.060 FAILED SPECIMEN	0.060 IN. AT 16,800 FAILED AT 20,600	ACOUSTIC EMISSION DETECTED CRACK INITIATION
11: TITANIUM	0.020 0.060	26,150 30,950	ACOUSTIC EMISSION DETECTED CRACK INITIATION & PROPAGATION
12: TITANIUM	0.050	38,340	ACOUSTIC EMISSION DETECTED CRACK E-O SENSORS TOOK FREQUENCY DATA
13: COMPLEX SPECIMENS – AL	0.050	16,750	ACOUSTIC EMISSION DETECTED CRACK
14: ALUMINUM COMPLEX	0.500	15,800	ACOUSTIC EMISSION HAD QUESTIONABLE SENSITIVITY
15: ALUMINUM COMPLEX	0.025 FRONT PLATE 0.050 BACK PLATE	15,090	ACOUSTIC EMISSION DETECTED CRACKS IN BOTH PLATES
16: ALUMINUM	0.050	17,500	ACOUSTIC EMISSION DETECTED CRACK
17: ALUMINUM COMPLEX	0.020	13,400	ACOUSTIC EMISSION DETECTED CRACK. MECHANICAL SENSOR HOLDERS MADE SYSTEM MORE SENSITIVE

R87-4543-009

Specimen 3 was tested at a load level of 27.5 ksi and cycled at a cycle rate of 2.5 cycles/sec. AE location events started to appear rapidly during the 5-min recording from cycles 84,100 to 84,800 as shown in Fig. 12. The test was stopped and inspection revealed a 0.080-in. crack at the hole site. The test was continued to demonstrate the effectiveness of the AE monitoring system in

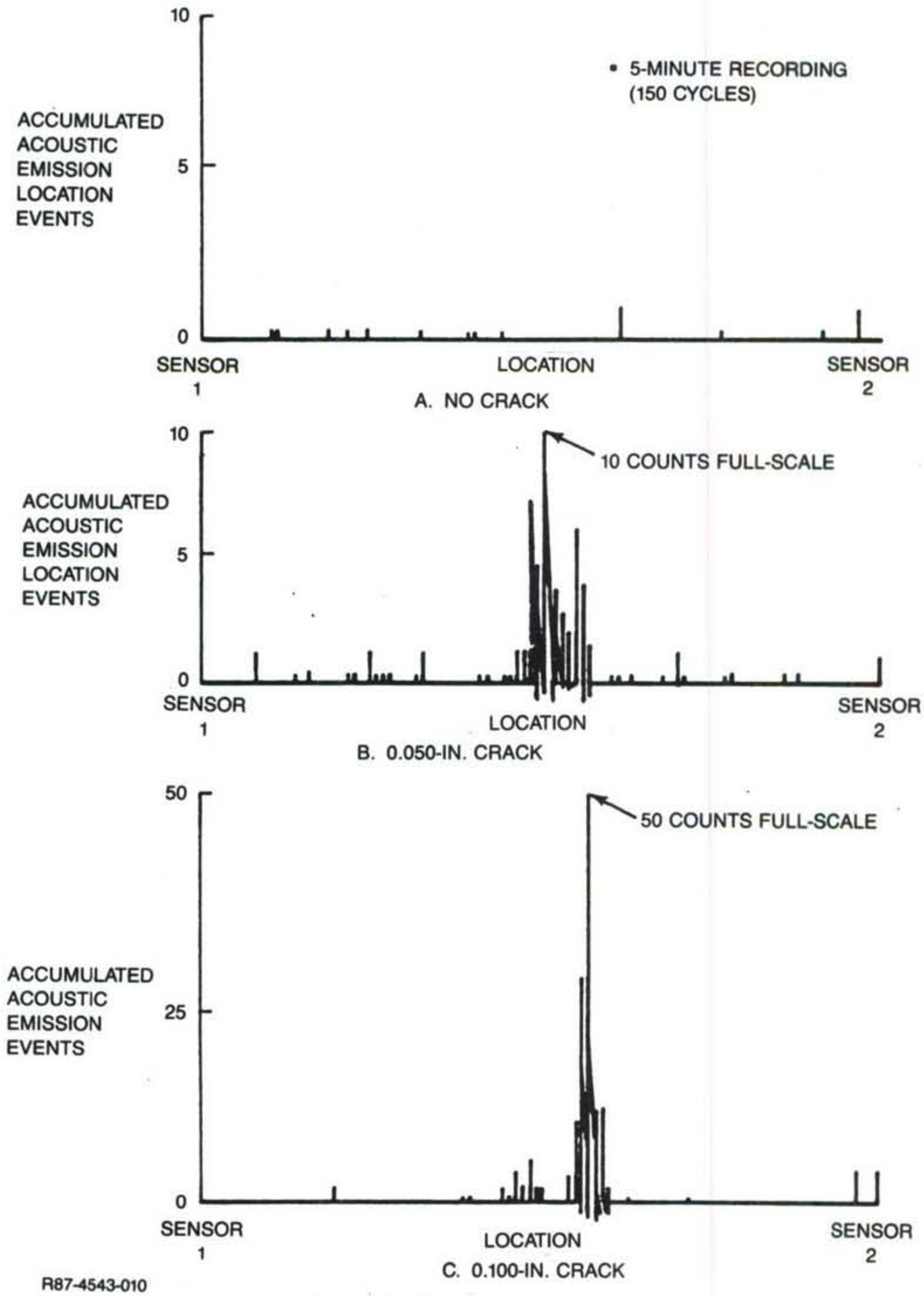

Fig. 9 Typical Acoustic Emission Data for Aluminum

detecting larger cracks. AE location events increased rapidly until cycle 88,000, when the test was stopped. The crack was inspected again and measured 0.250 in.

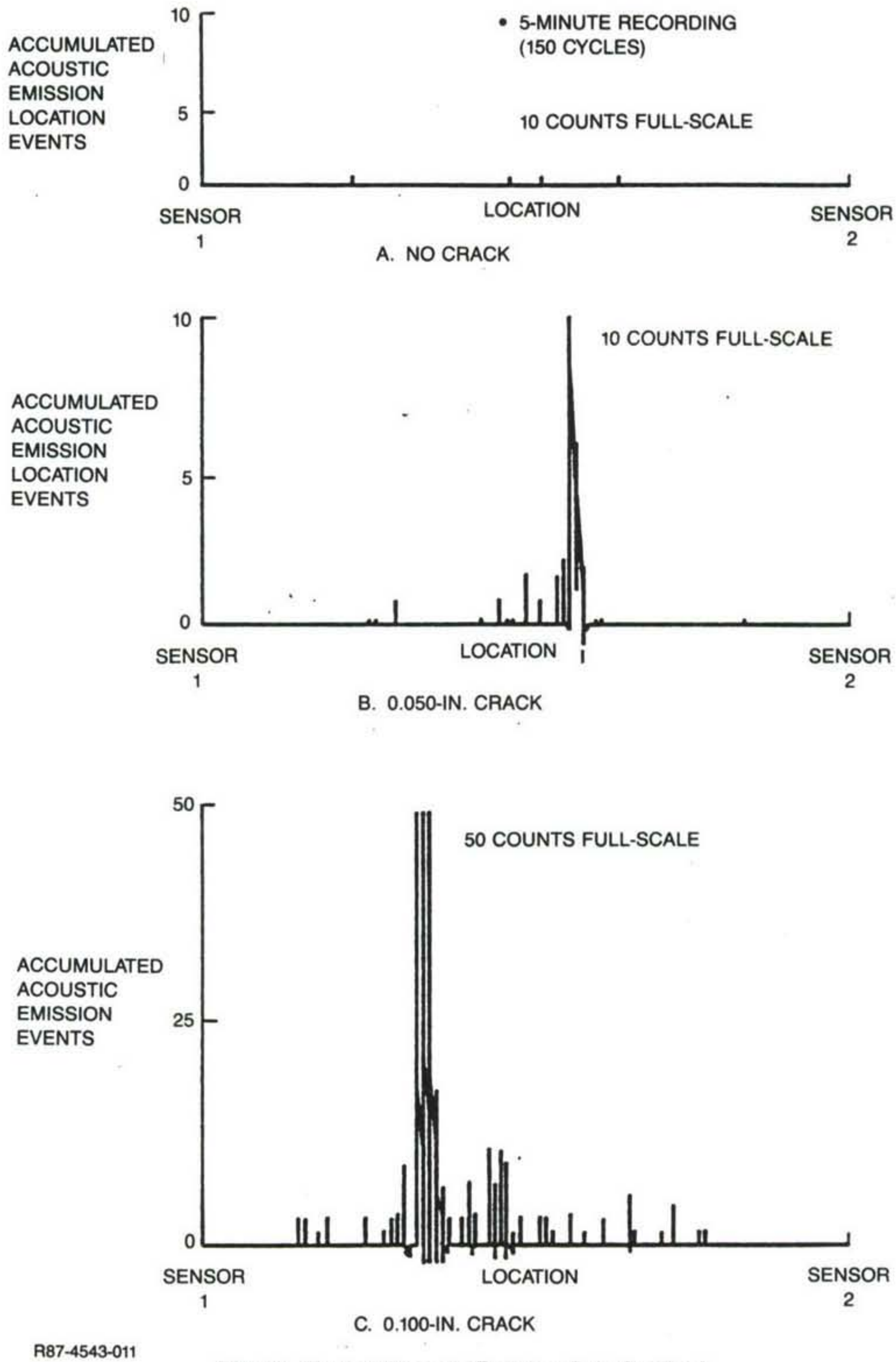

Fig. 10 Typical Acoustic Emission Data for Steel

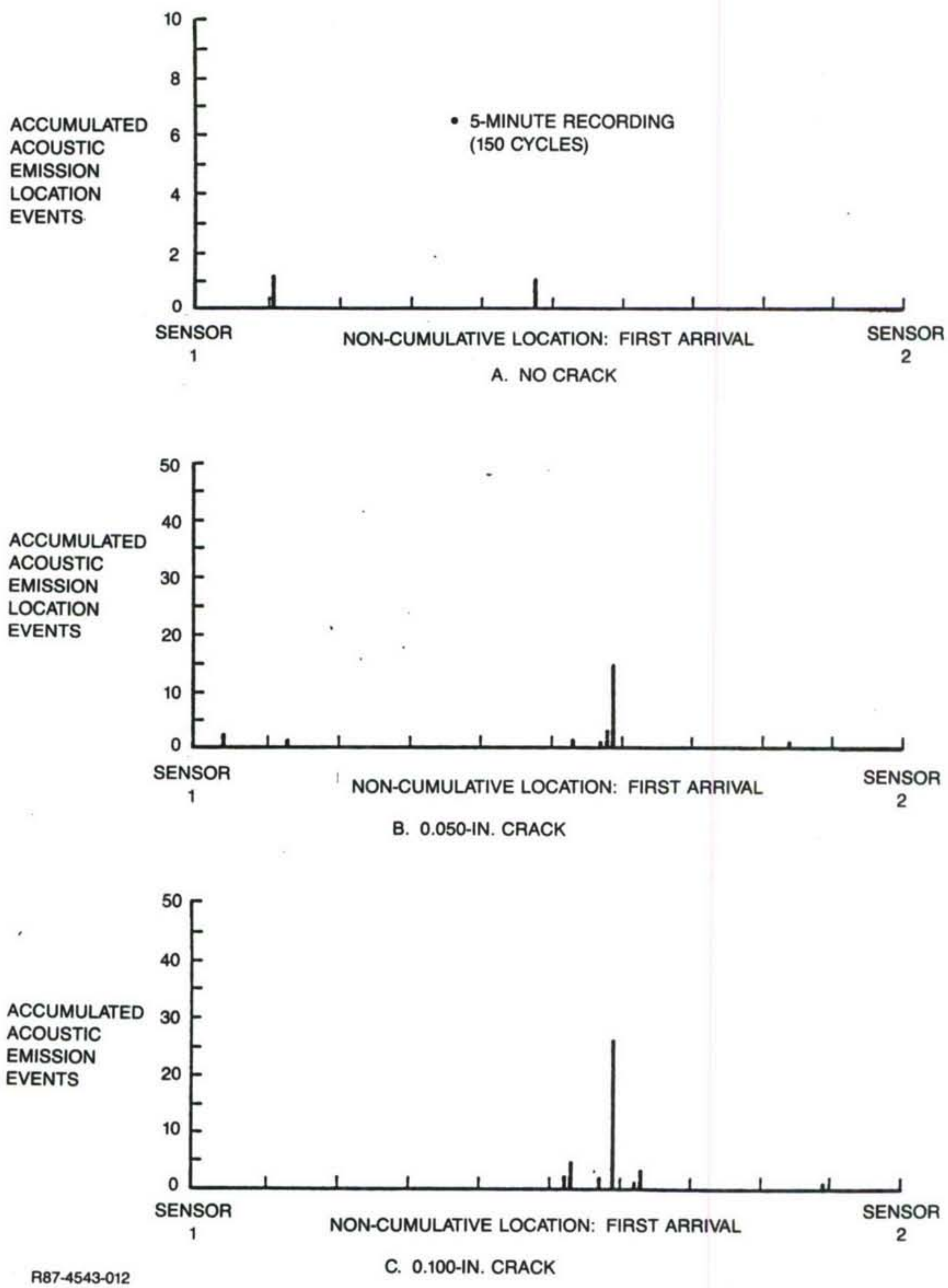

Fig. 11 Typical Acoustic Emission Data for Titanium

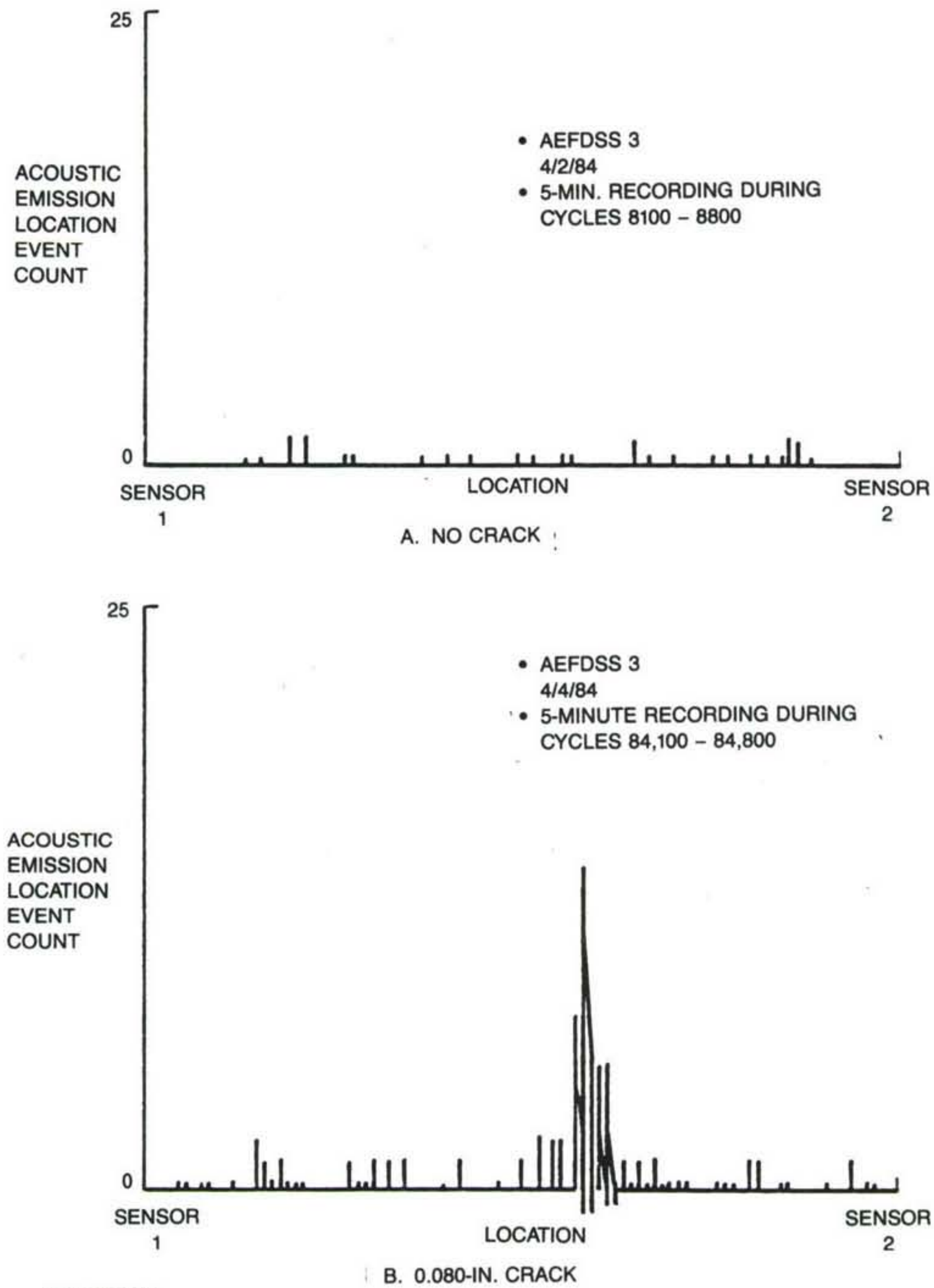

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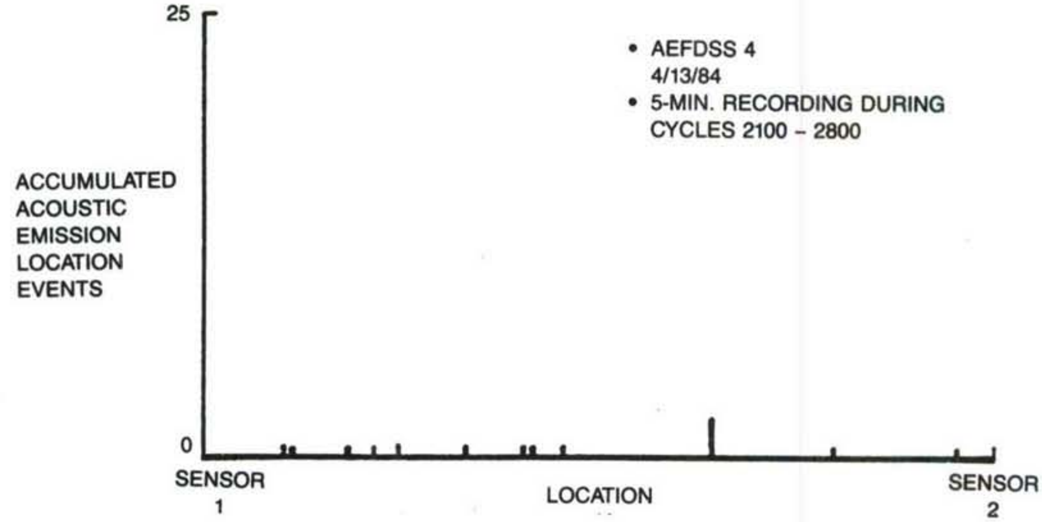
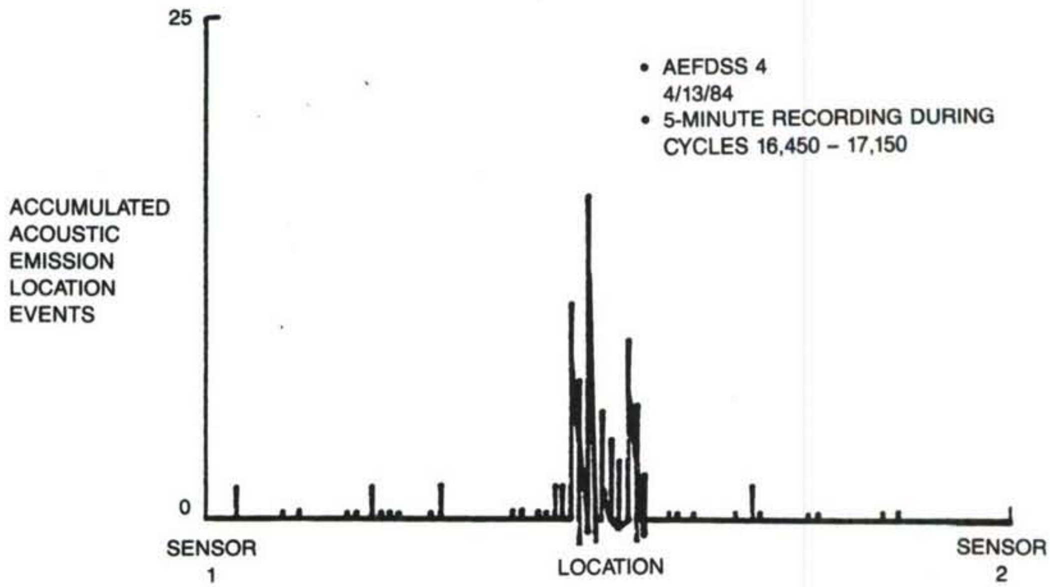
Fig. 12 Data for Specimen 3

Specimen 4 was fatigued at an increased load level of 29 ksi and a cycle rate of 2.5 cycles/sec. The load was increased to allow for a shorter duration fatigue test than Specimen 3. Figure 13 shows the buildup of AE location events from 16,450 to 17,150 cycles. The test was stopped and inspection revealed a 0.100-in. crack at the hole site. It was determined that the reason



A. NO CRACK



B. 0.100-IN. CRACK

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Fig. 13 Data for Specimen 4

for cracks larger than 0.050 in. being detected in Specimens 3 and 4 was the fast cycle rate being applied to the specimens.

In order to determine whether the fast cycle rate was affecting the size of the crack detected, Specimen 5 was cycled at 2.5 cycles/sec until the first

AE location event appeared; then a 5-min recording was taken at a slower cycle rate (~ 1 cycle/sec). Figure 14 shows a buildup of AE location events during cycles 13,180 to 13,430. The test was stopped and inspection revealed a 0.020-in. crack at the hole site. The slower cycle rate allowed for detection of a crack smaller than 0.050 in.

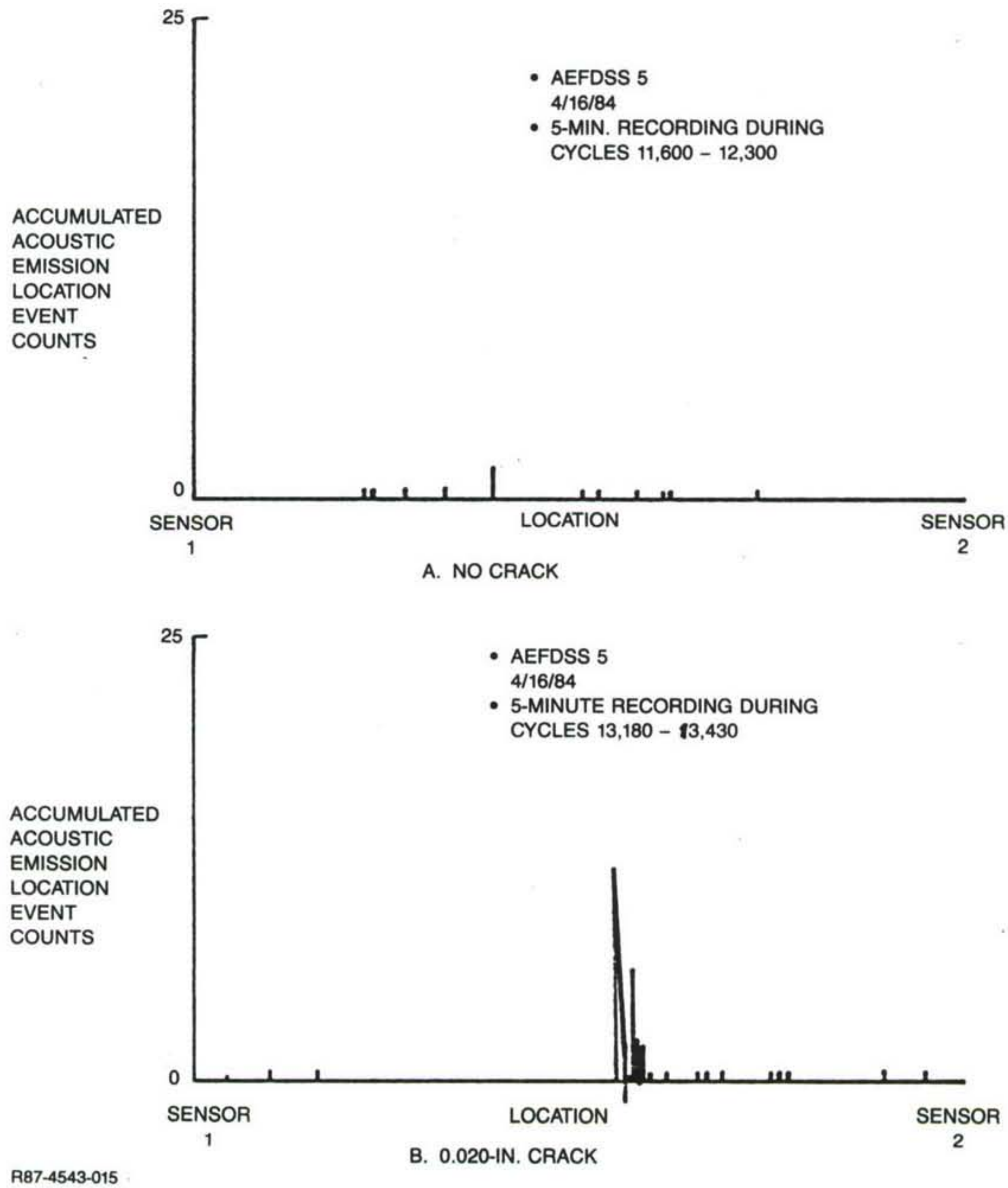

Fig. 14 Data for Specimen 5

Data from Specimen 7 (Fig. 15) shows AE location events accumulating during cycles 11,300 to 12,200. The test was stopped and subsequent inspection

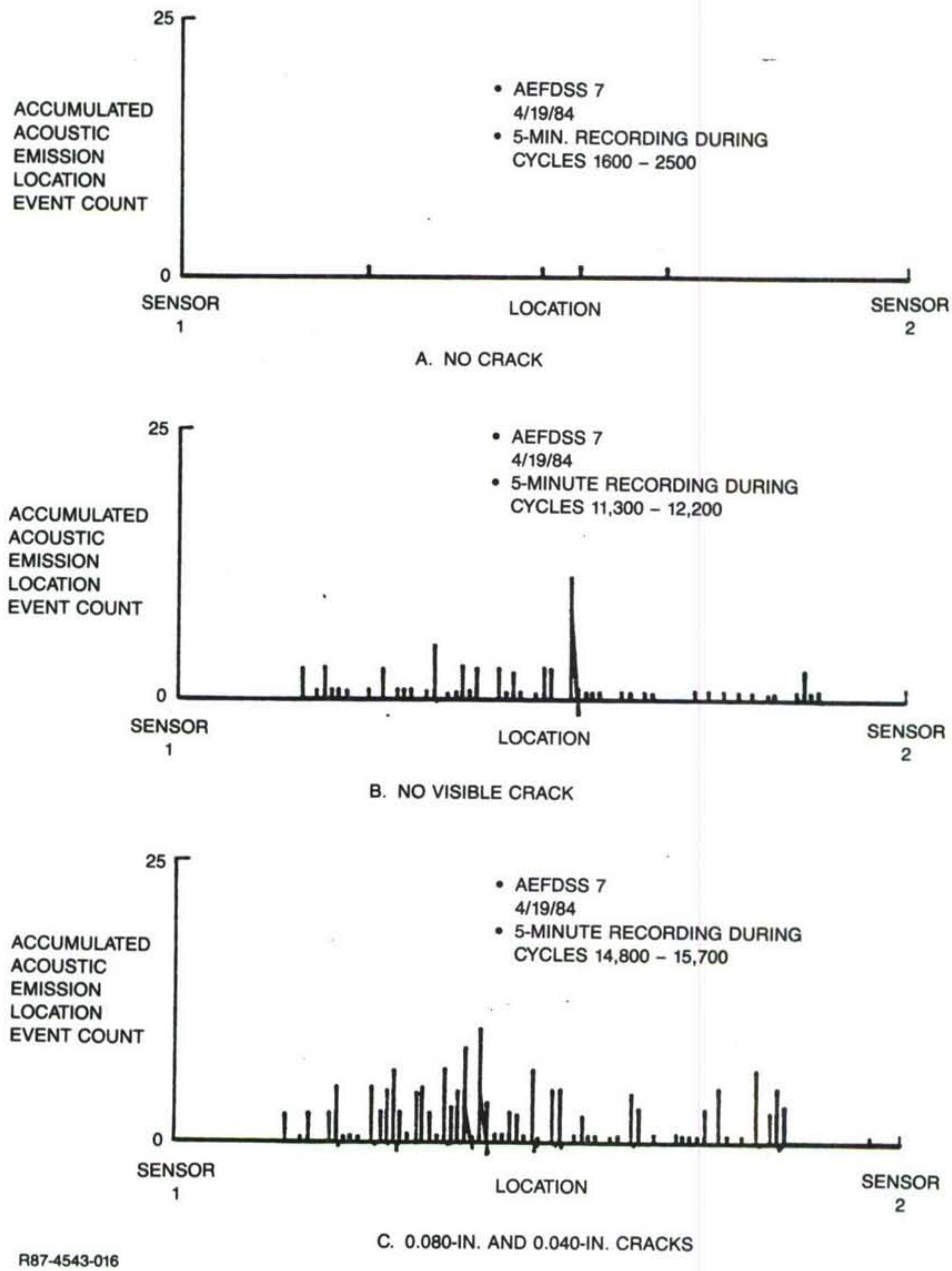

Fig. 15 Data for Specimen 7

with eddy current techniques revealed no crack indications. An increase in AE activity is shown during cycles 14,800 to 15,700. The AE locations shown in Fig. 14 show an increase in AE activity with scattered locations. An inspection revealed two cracks in the hole measuring 0.080 in. and 0.040 in. Multiple cracking within the area is the cause for the scattered locations shown. Figure 16 shows the definitive location of the two cracks during cycles 16,400 to 17,300. Many AE signals are accumulating at the location to the left while a few signals are still accumulating in the original location to the right. The crack on the left grew from 0.040 in. to 0.090 in. (0.050-in. growth) while the crack on the right grew only 0.020 in.

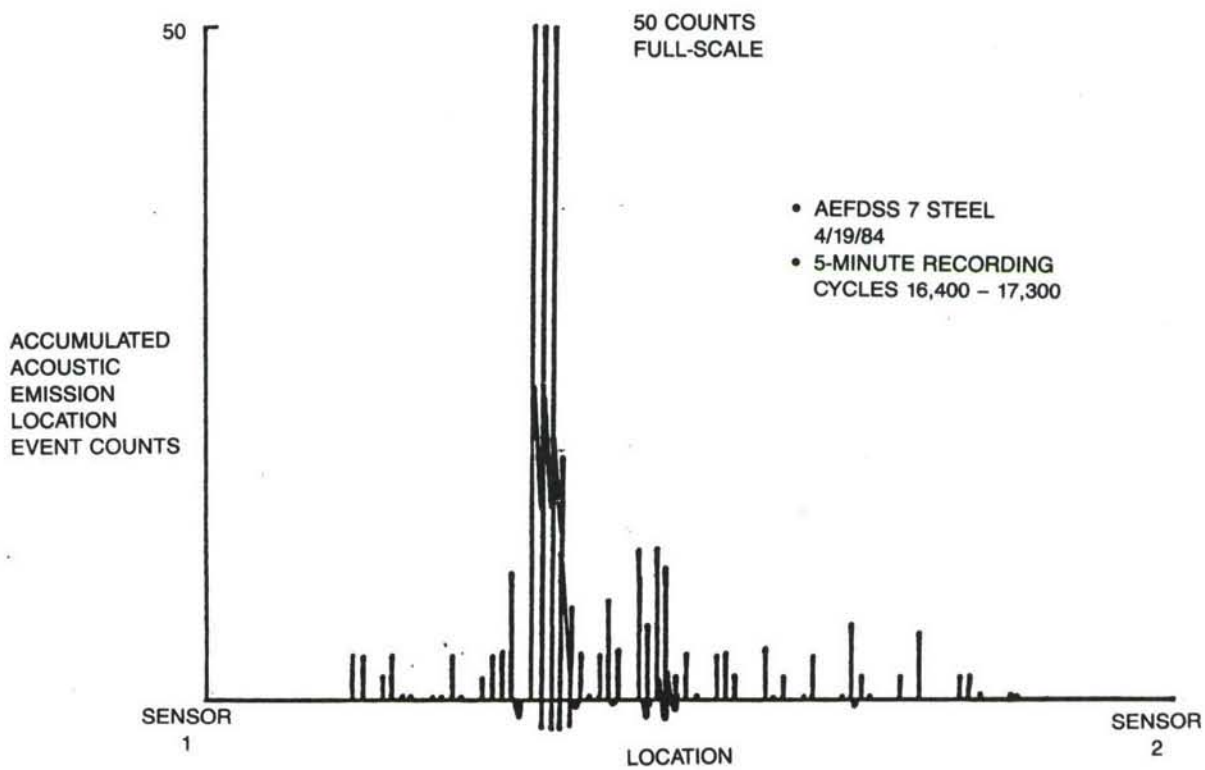

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Fig. 16 Data for Specimen 7: Signal Increase

Data from Specimen 8 shown in Fig. 17 shows AE location events accumulating during cycles 15,800 to 16,700. The test was stopped and the crack measured 0.060 in.

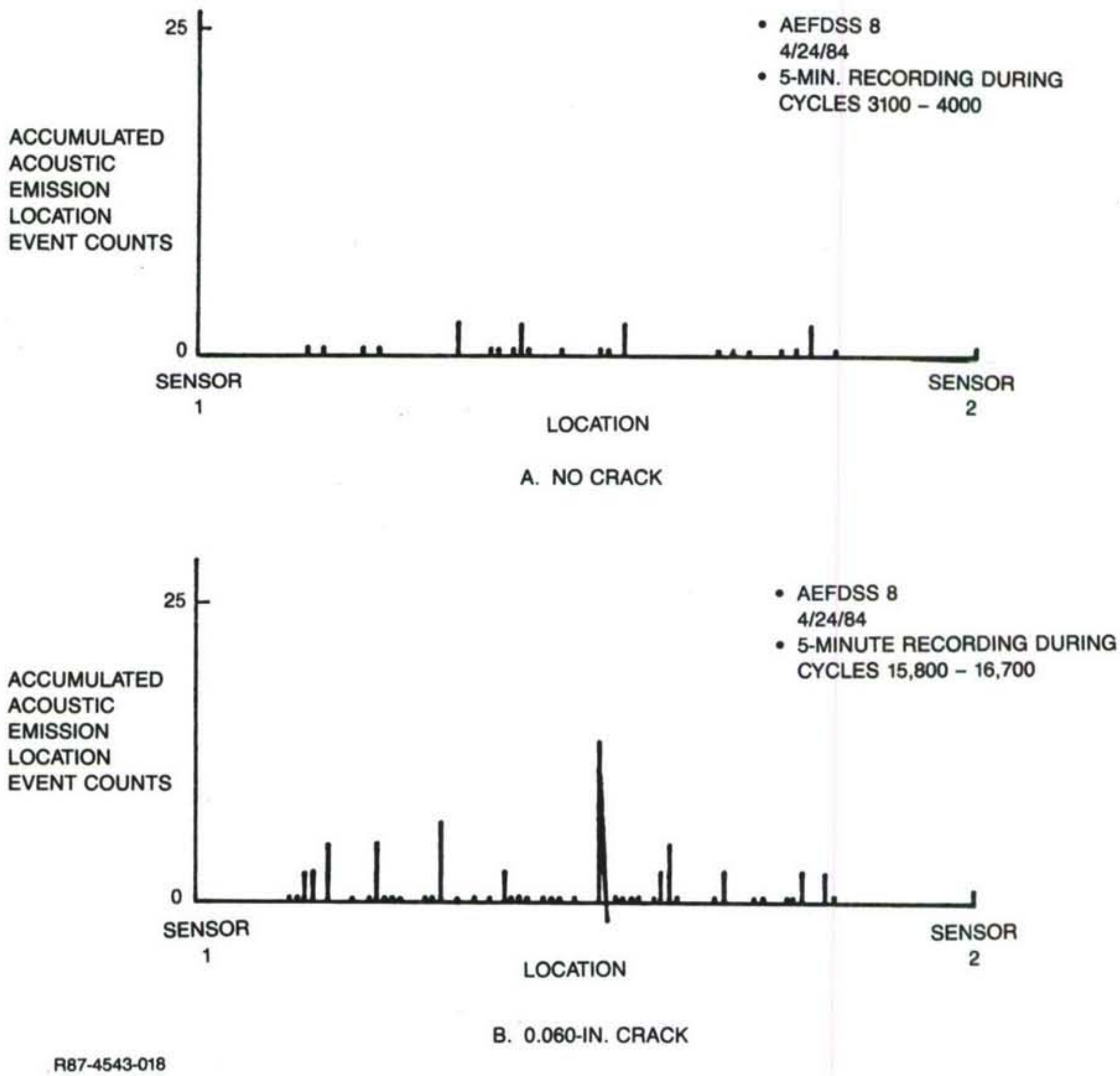


Fig. 17 Data for Specimen 8

Specimen 9 was monitored simultaneously with the Physical Acoustics Model 3400 system. Figure 18B shows AE location events accumulating during cycles 16,400 to 17,300. The test was stopped and inspection revealed a 0.020-in. crack at the hole site. The test was restarted to evaluate the P.A.C. 3400 system's crack capabilities for a propagating flaw. Figure 18C shows AE events accumulating very distinctly during cycles 18,900 to 19,000 (100 cycles vs 900 cycles on initial recording). The crack was measured and found to be 0.200 in. The P.A.C. 3400 system was found to be equivalent to the Grumman AE system in its crack detection and noise discrimination capabilities.

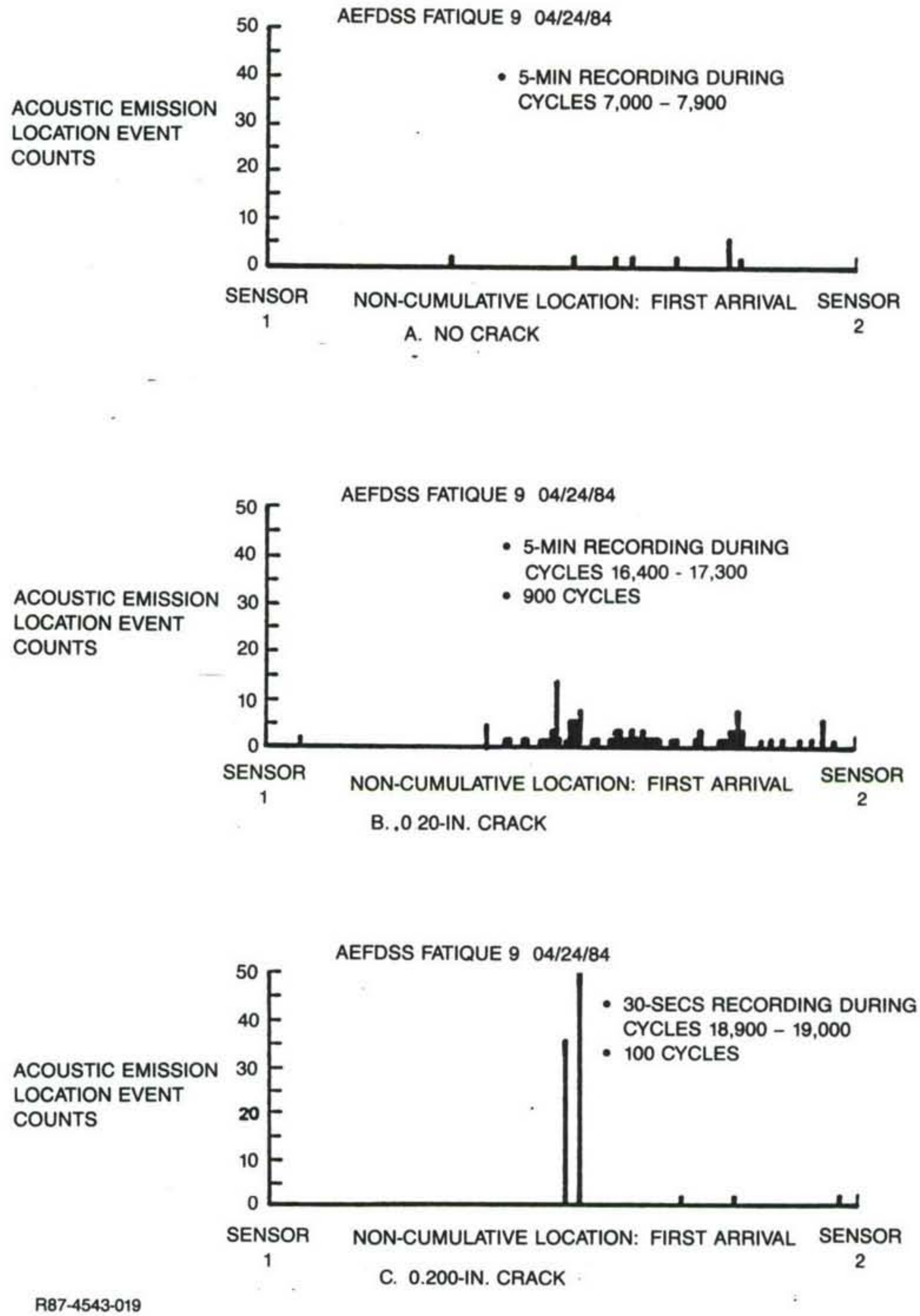
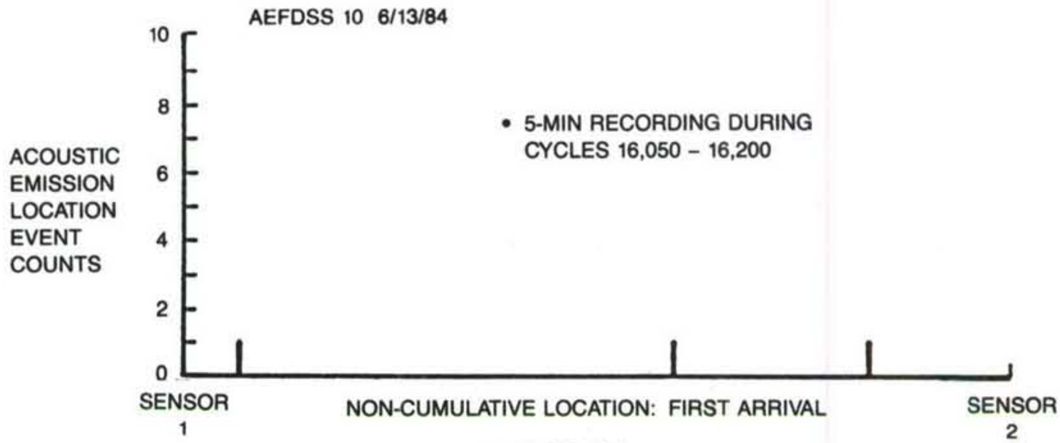
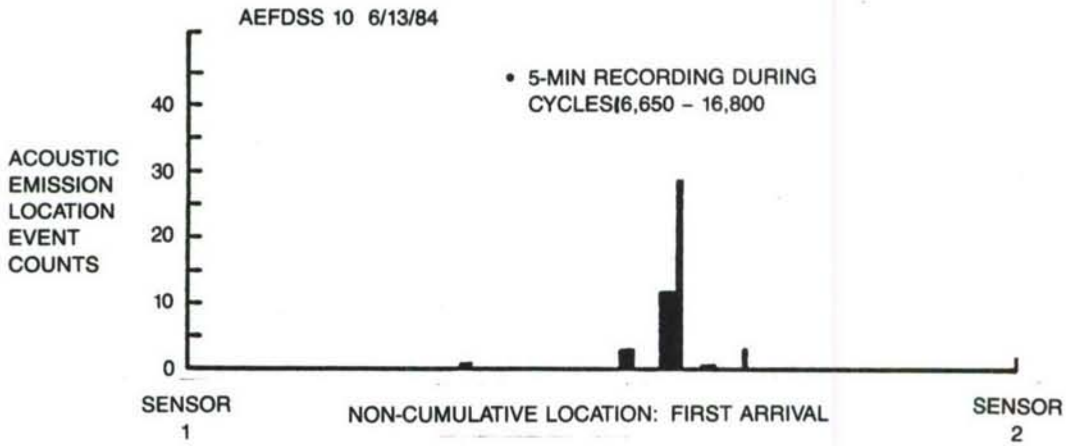


Fig. 18 Data for Specimen 9

Specimen 10 was monitored with the P.A.C. Model 3400 system. Figure 19B shows AE location events increasing rapidly during cycles 16,650 to 16,800 (50 counts full-scale). The test was stopped and inspection revealed a 0.060-in.



A. NO CRACK



B. 0.060-IN. CRACK

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Fig. 19 Data for Specimen 10

crack at the hole site. The test was continued in order to generate AE location data for a propagating crack in titanium. AE location events continued increasing until the specimen failed at 20,600 cycles.

Specimen 11 was monitored with the Grumman AE monitoring system in order to compare the results with the P.A.C. 3400 system on titanium. Figure 20B shows a buildup of AE location events during cycles 26,000 to 26,150. An eddy current and visual inspection revealed a 0.020-in. crack at the hole site. The test was restarted and Fig. 20C shows a slightly larger buildup of AE location events during cycles 30,800 to 30,950. The test was stopped and inspection revealed a 0.060-in. crack at the hole site. Specimens 10 and 11 also proved the equivalency of the Grumman AE monitoring system and the P.A.C. 3400 system. The P.A.C. 3400 system was used for the remainder of the fatigue test program.

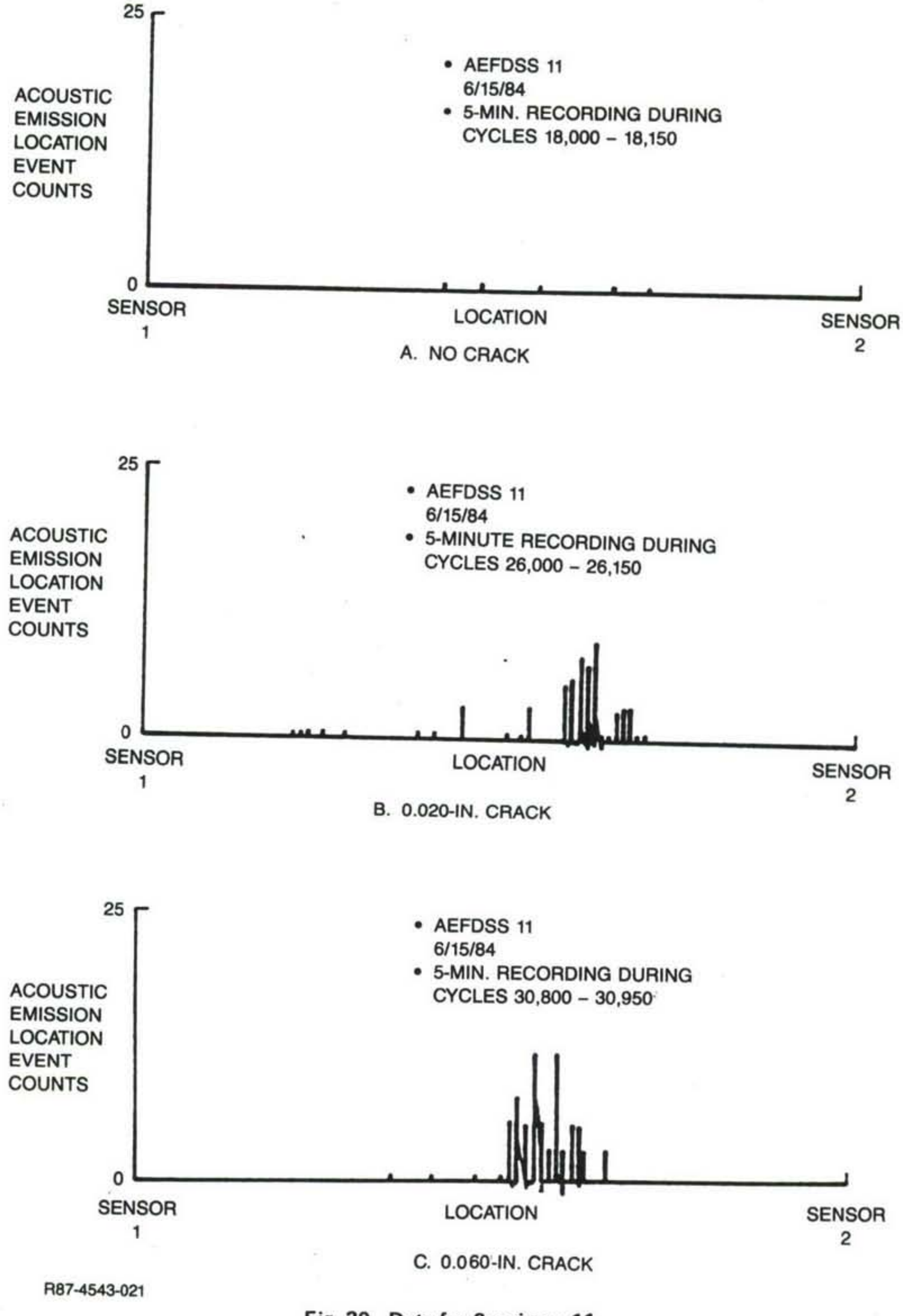


Fig. 20 Data for Specimen 11

2.4.4.2 Multiple Fastened/Stacked Specimens

Five multiple fastened stacked specimens (shown in Fig. 3B) were tested and monitored with the PAC 3400 system for crack initiation and propagation.

The configuration was designed to simulate typical airframe construction, and the specimens were constructed out of aluminum to minimize construction costs. Data for Specimens 13 through 17 are shown in Fig. 21 through 27.

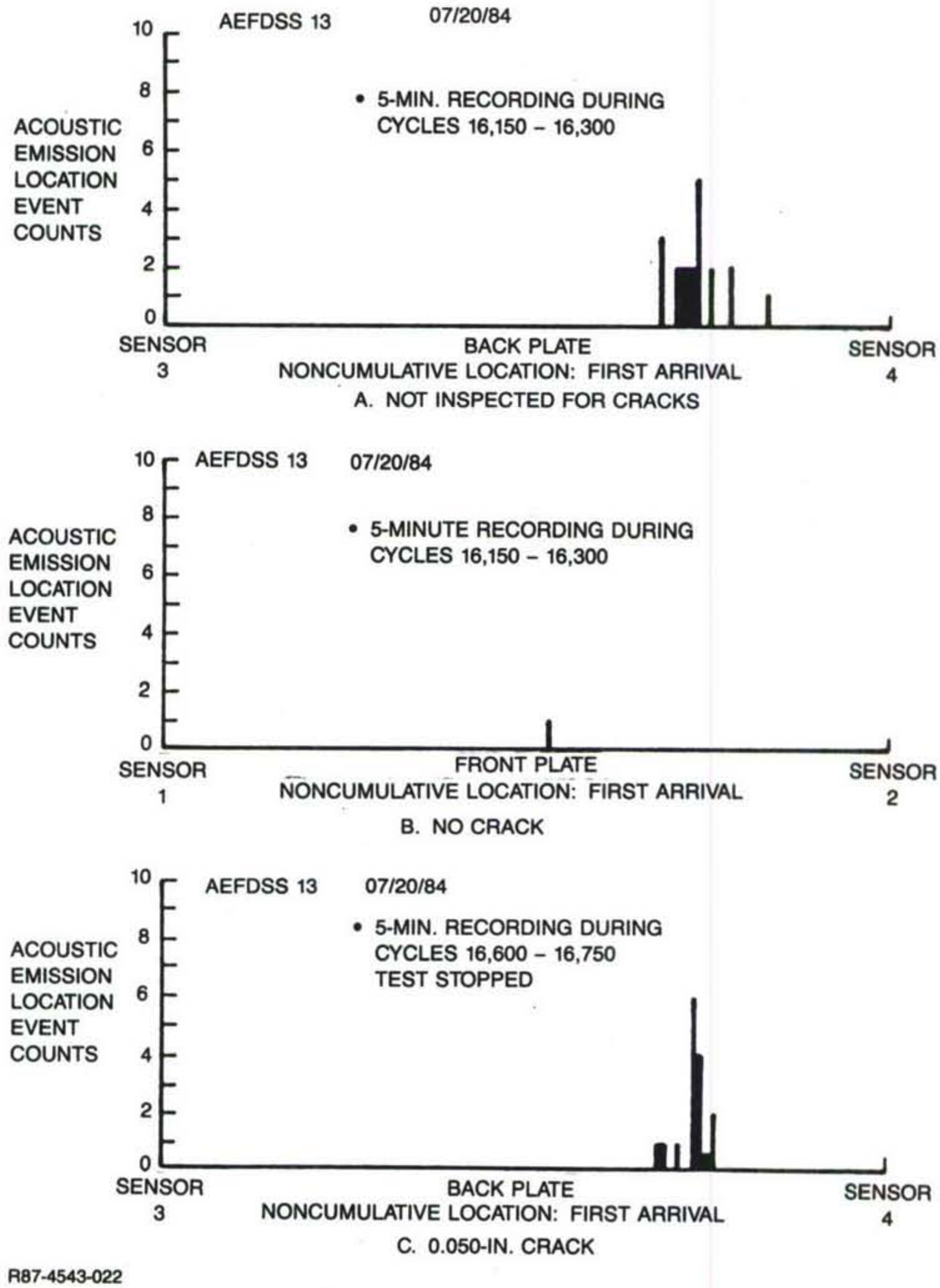


Fig. 21 Data for Specimen 13

Figure 21 shows AE location events generated during cycles 16,150 to 16,300 and 16,600 to 16,750 in the bottom hole of the back plate for Specimen

13. No AE location event signals were generated from the front plate shown in Fig. 21B. The test was stopped at 16,750 cycles, and both front and back plates were inspected visually and with eddy current. A 0.050-in. crack was found in the bottom hole of the back plate. No cracks were found in any of the other holes.

Specimen 14 shown in Fig. 22 through 24 represents an interesting case. AE location events were generated on front and back plates early in the fatigue life (cycles 6300 to 6900 and 6950 to 7100), as shown in Fig. 22. The test was

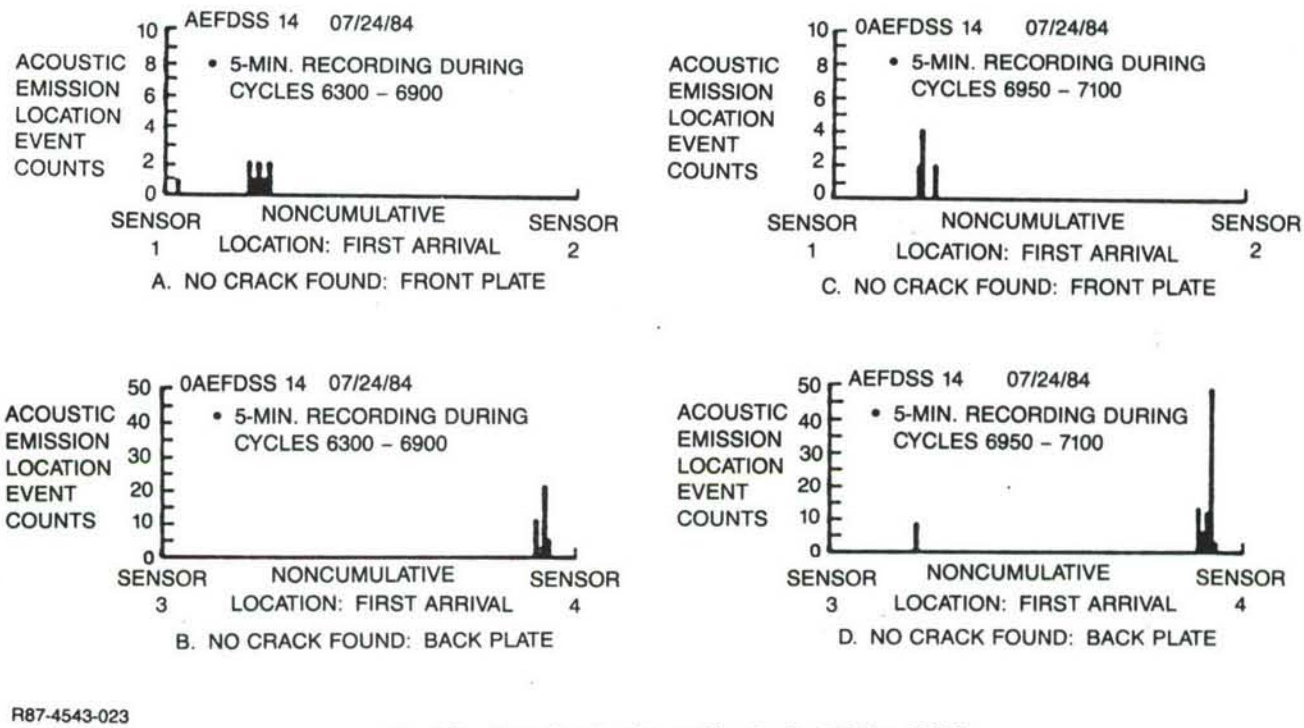


Fig. 22 Data for Specimen 14: Cycles 6300 to 7100

stopped, the specimen was inspected with eddy current, nital etched, and visually inspected, and no cracks were found in any of the holes. The specimen was placed back in the test fixture, the sensors were adhered, and the system calibrated. Figure 23 shows a few AE location event counts being generated during cycles 10,250 to 10,400 and cycles 14,450 to 14,600. This figure shows little AE location event activity until cycles 15,650 to 15,800 (Fig. 24), at which AE location event signals then began to appear rapidly on both front and back plates. The test was stopped and inspection revealed a 0.500-in. crack in the top hole of the front plate, and a 0.100-in. crack in the top hole of the

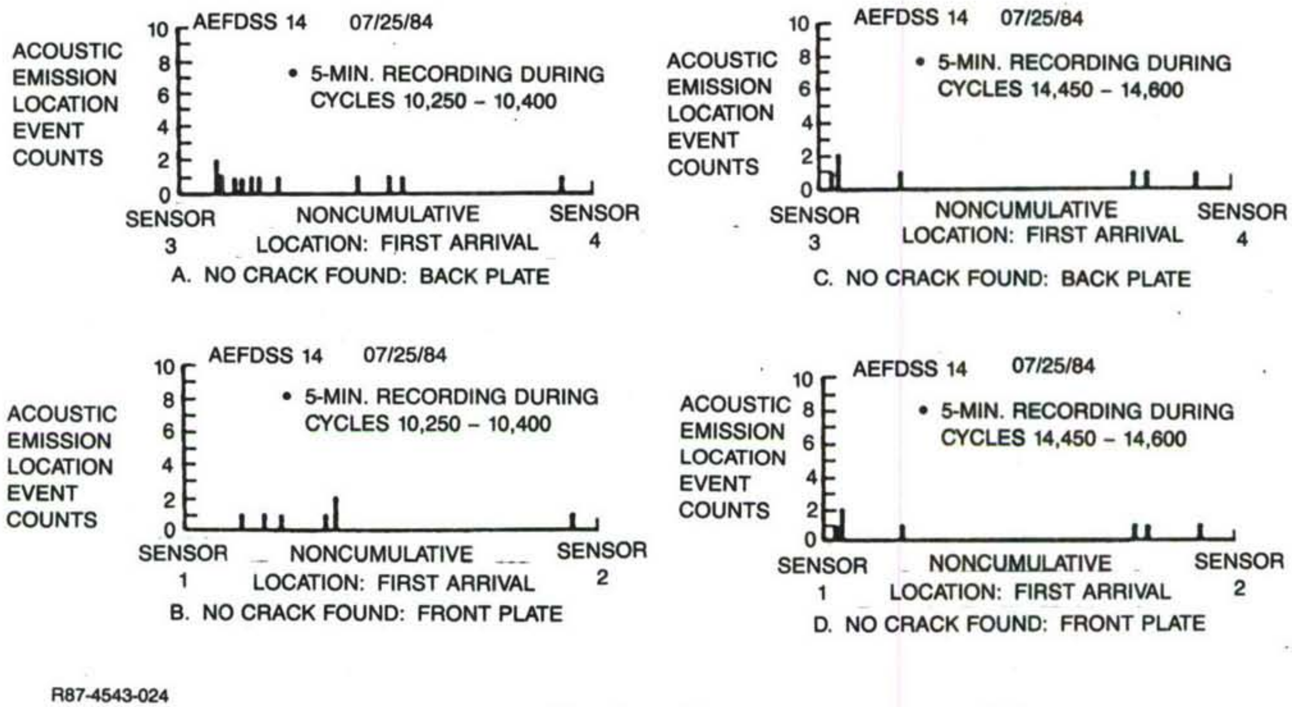


Fig. 23 Data for Specimen 14: Cycles 10,250 to 14,600

back plate. A possible explanation for the poor results is that the crack was initiated during the period from cycles 6,300 to 7,100, and was therefore too small to be detected by Nondestructive Testing (NDT) techniques. When the specimen was replaced in the test fixture, the sensors were properly adhered to the surface and calibrated. However, there were delays between the adhering and calibration of the system, the restart of the system, and the restart of the test. The delay may have resulted in degrading of the adhesive bond between the sensors and the test specimen, resulting in a loss of sensitivity in the energy transfer between the test specimen and the piezoelectric crystal. The crack was propagating between cycles 7,100 and 15,650, and the amplitude of the sonic energy released was insufficient to trigger the location system. When the crack grew very large, the amplitude of the sonic energy released became high enough to trigger the location system, and the test was stopped. Improvements in calibration and sensor couplant techniques were made to prevent this situation in Phase II of the program.

Data for Specimen 15 are shown in Fig. 25. AE location events were generated during cycles 15,000 to 15,090 on front and back plates. The AE

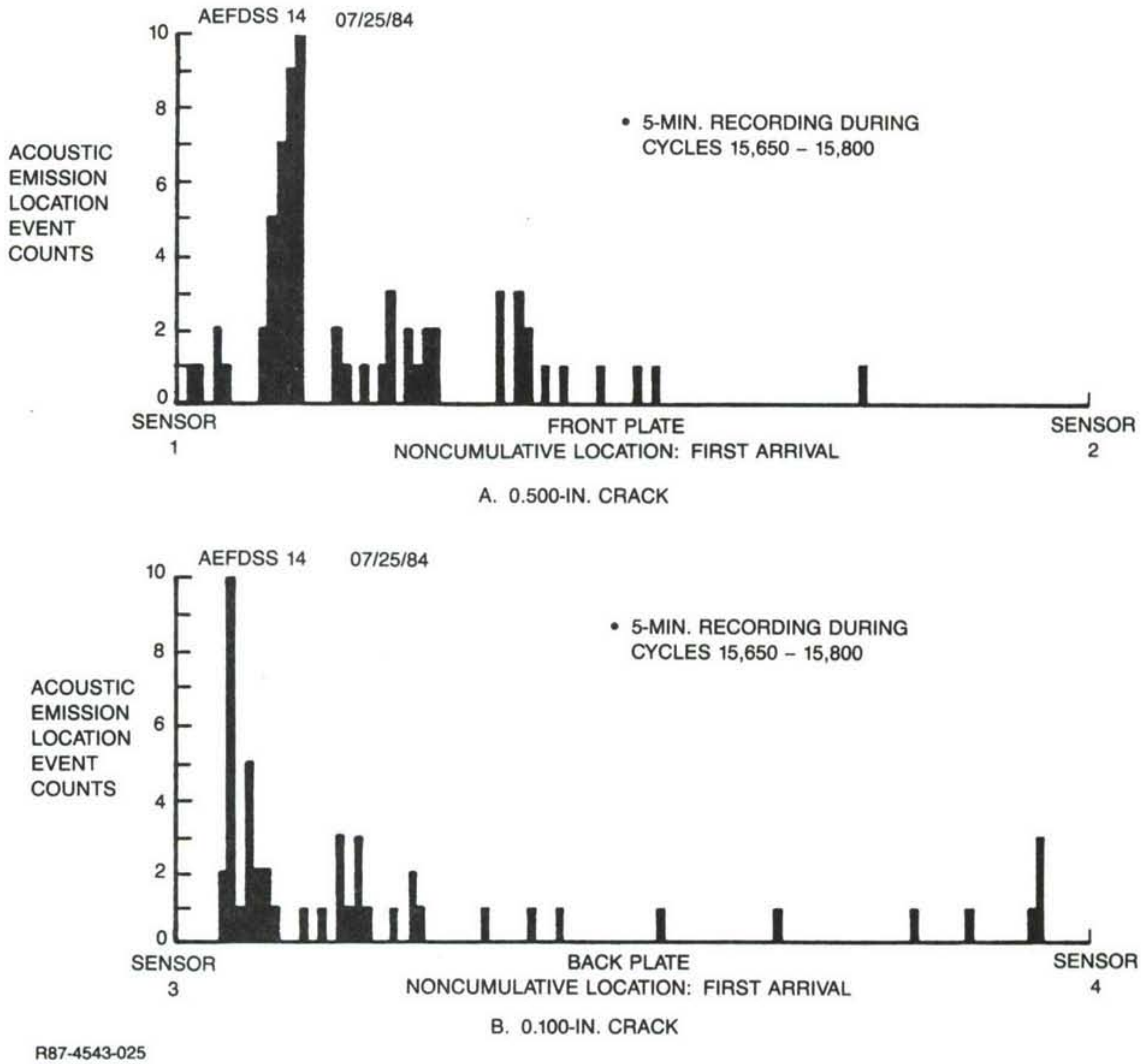
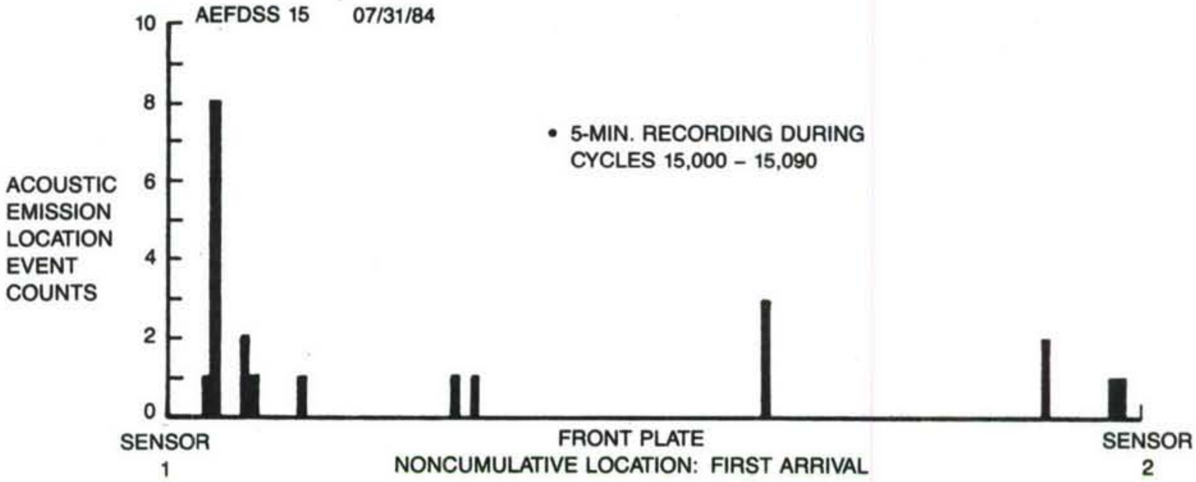
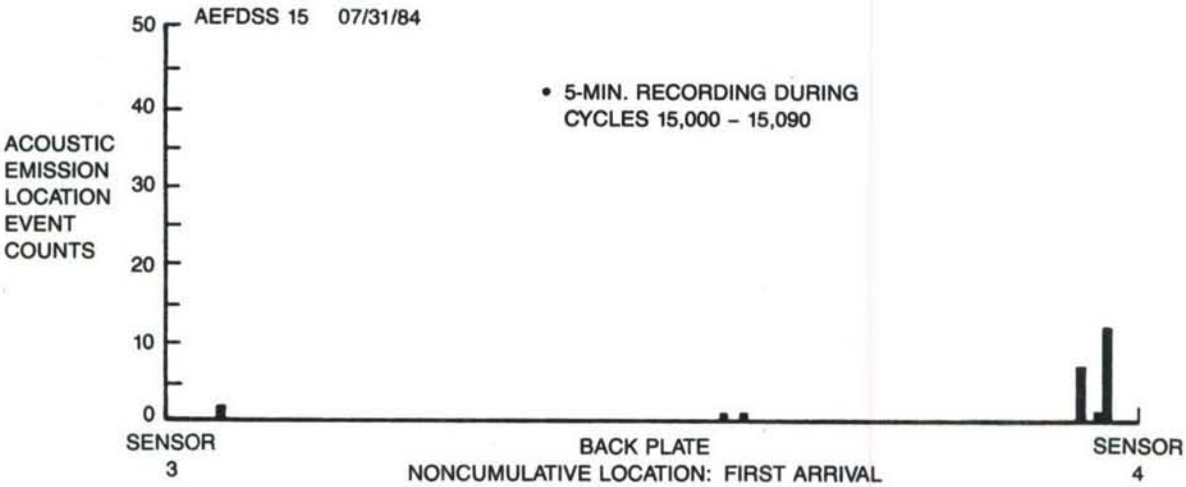


Fig. 24 Data for Specimen 14: Cycles 15,650 - 15,800

location events were being generated so rapidly for the duration of the recording that the full 5-min (150-cycle) recording was stopped after 3 min (90 cycles), and then the test was stopped. Inspection revealed a 0.025-in. crack on the front plate and a 0.050-in. crack on the back plate. This demonstrated the fact that the PAC 3400 system could detect cracks on two plates simultaneously, and also that the faster the crack growth, the more rapidly AE location events are generated.



A. 0.025-IN. CRACK



B. 0.050-IN. CRACK

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Fig. 25 Data for Specimen 15

Data for Specimen 16 is shown in Fig. 26. AE location events were generated on the back plate top hole during cycles 17,350 to 17,500. The test was stopped and inspection revealed a 0.050-in. crack in the top hole of the back plate.

Specimen 17 was tested with holding fixtures for the sensors to attempt to overcome the sensor coupling problems encountered during the test program, particularly the sensitivity problems encountered on Specimen 14. The fixtures were designed to hold the sensors down to the test specimen while coupling the sensors with a heavy-grade oil, thus preventing the sensors from losing coupling to or falling off of the test specimen.

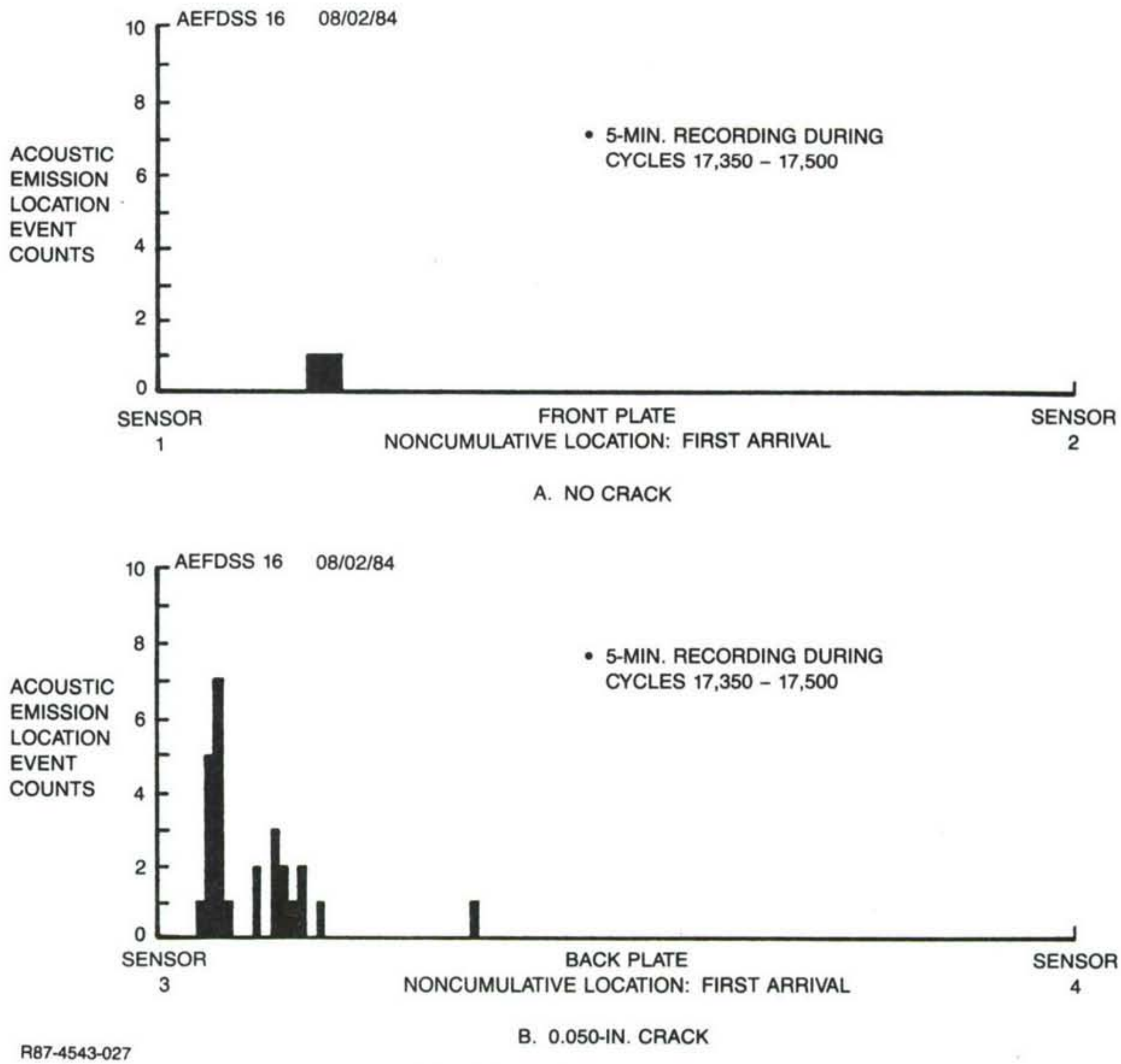

Fig. 26 Data for Specimen 16

The results of the experiment proved to be encouraging: Fig. 27 shows AE locations events generated on the top hole of the back plate more rapidly than on the previous tests (50 count full-scale) during cycles 12,350 to 12,500 and 13,250 to 13,400. The test was stopped and inspection revealed a 0.020-in. crack on the top hole of the back plate. These results indicate that the reliability of the system to detect a 0.050-in. crack can be improved dramatically with the use of mechanical hold-down fixtures and oil couplant rather than the conventional method of bonding the sensors to the surface of the specimen.

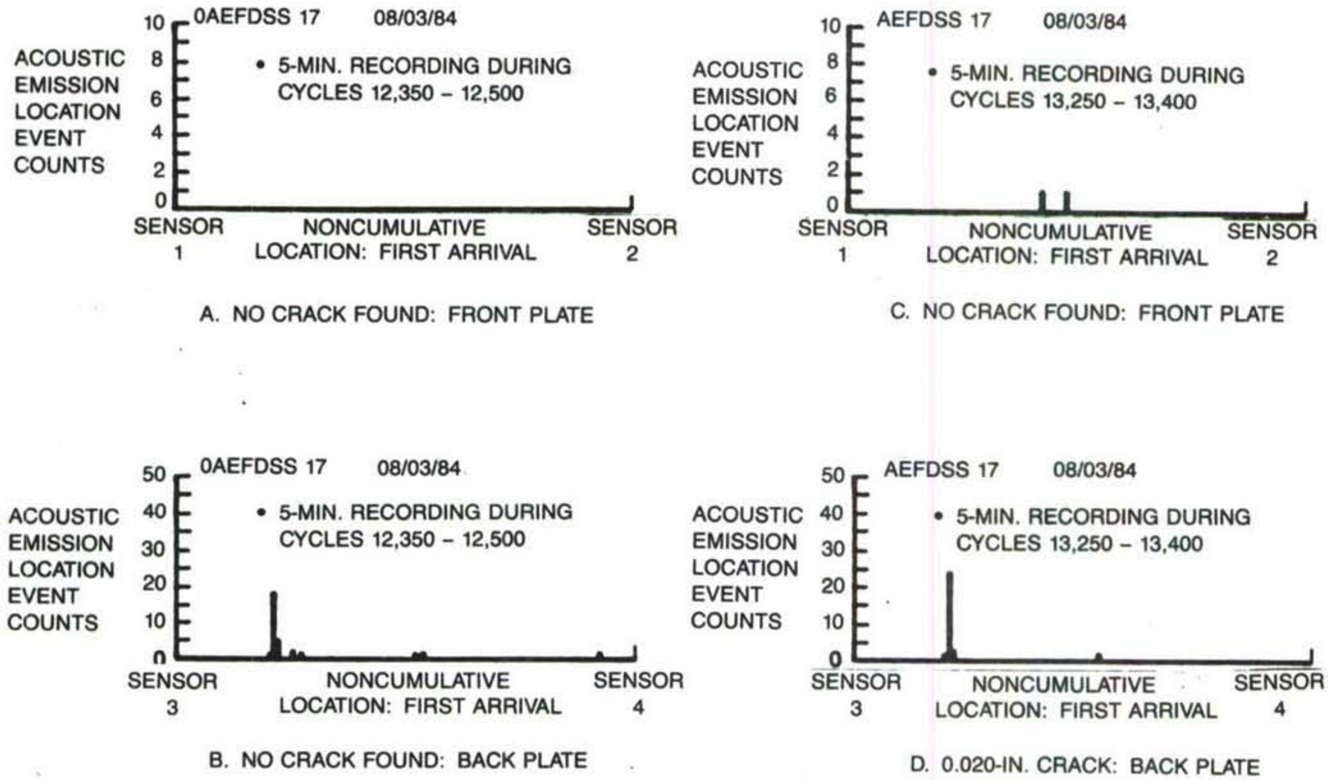

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Fig. 27 Data for Specimen 17

2.4.5 Conclusions

The AE technique can reliably detect 0.050-in. cracks under realistic fatigue test conditions if a prior knowledge of the system's capabilities are known and frequent calibrations are included. The single-hole dog-bone specimen evaluations provided the prior knowledge that enabled early detection of the more complex multi-hole specimens. Variable results did occur, which appeared to be a result of inadequate/changing transducer coupling characteristics. Improved coupling techniques and more frequent sensitivity calibration tests should overcome this problem.

2.5 TRANSDUCER CLAMPS

During Phase I of the program a problem arose that was solved by a specially developed technique. It became evident that during a fatigue test that lasted more than one day, the transducers attached with cyanoacrylate (super glue) to the specimen experienced signal losses due to inadequate

coupling. This condition was found to be caused by a weakened intermittent glue bond that was adequate enough to hold the transducer in place, but loose to the point of impeding the transmission of the AE signals between the surface of the specimen and the transducer face.

The degree to which the bond line attenuated the signal across its interface varied, which resulted in a reduced confidence in the validity of signals.

The use of other coupling media, such as gels and grease, did not exhibit the same problem. In fact, the problem was only apparent over long periods of testing with cyanoacrylate. The use of gels and grease require some other means of securing the transducer to the specimen, whereas the cyanoacrylate was the couplant and the securing device. The approach of mechanically securing transducers to the specimen with fixtures is very often impossible and bonding is usually the only alternative.

A device was therefore developed which takes advantage of both of the positive qualities of bonding and grease (see Fig. 28). The device is bonded in place with cyanoacrylate, but the signal does not pass through the glue line. The clamp presses the transducer onto the specimen which is coupled with a gel or grease. When the glue line weakens it does not affect the transmissive characteristics of the interface.

This transducer clamp was used throughout the bulkhead tests, which ran over a week at a time, and was found to be very reliable for this use.

2.6 GRAPHICS SOFTWARE DOCUMENTATION

The central feature of the AEFDSS is its ability to graphically display the fatigue damage data on a pictorial representation of the specimen under test. Associated with this feature is the operator's ability to draw an outline of the specimen onto the display for any given component chosen for AE monitoring. As a result of these features, the system greatly reduces the operator's burden in analyzing the result of a monitoring session.

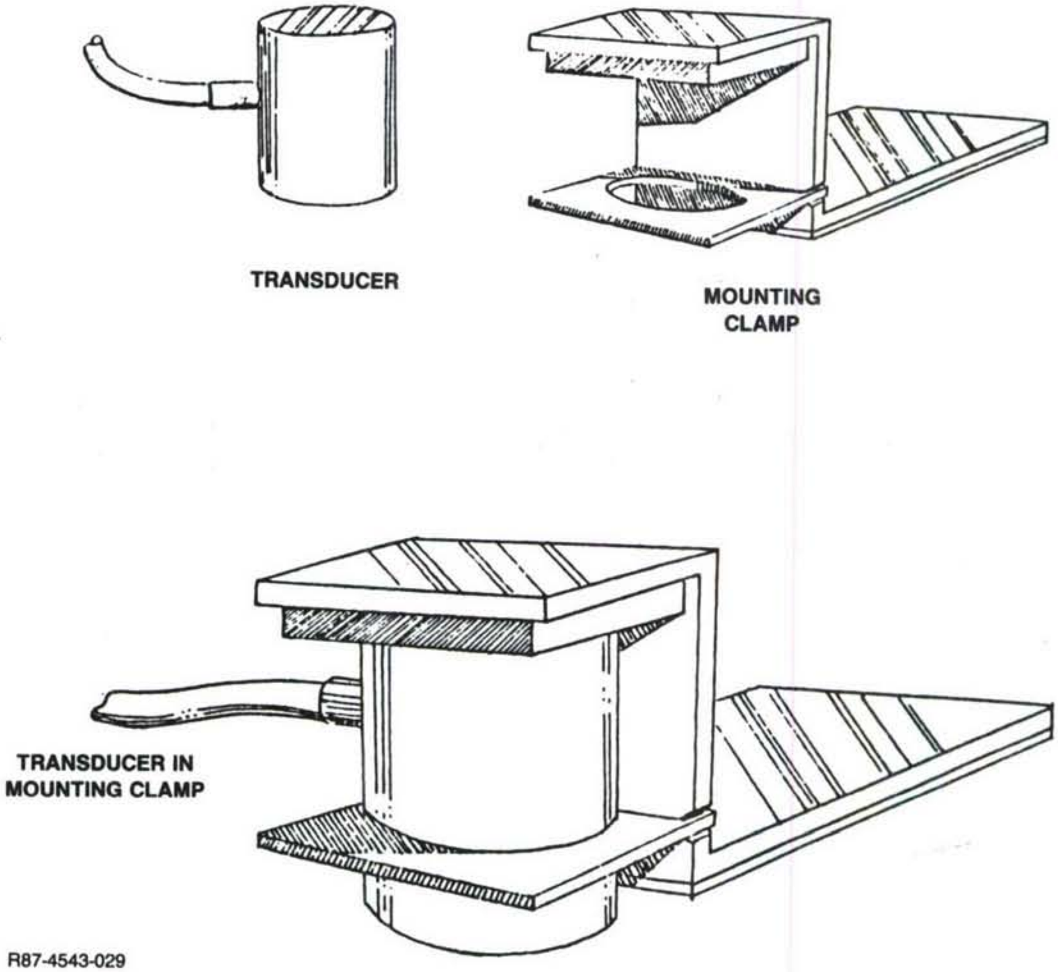

Fig. 28 Illustration of Transducer Clamps Showing Them Assembled and Disassembled

Provided with the system is software which interconnects the graphics display board with the SPARTAN data acquisition system. Within this software are programs for entering the part outline and transducer placement on the part. Additional programs are provided to save the outlines and calibration data required to make the graphics/SPARTAN link.

The documentation for the operation of the software is found in the Appendix of this report.

3 - SYSTEM DEVELOPMENT

3.1 INTRODUCTION

The graphics capability requirements were determined to be quite straight forward, with the need for a digitizing tablet (to input a graphic representation of the part and sensor locations) to be interfaced into the Spartan 3000 computer module and associated input and display software. However, it was realized that such an effort could take considerable time and therefore should not hold up the more challenging development efforts involving discrimination and location.

As a result of the preliminary feasibility studies, the AE technique was selected for further development. It was anticipated that complex structures would affect the discrimination and location capabilities and necessitate further refinements. In order to identify these additional requirements, an "off the shelf" Spartan 3000 system was evaluated on complex specimens. The following are discussions of these evaluations.

3.2 INITIAL COMPLEX CONFIGURATION EVALUATIONS

3.2.1 The NADC Box Beam

The first system evaluation of the Spartan 3000 entailed a test on the NADC Box Beam structure, a 4-ft long beam containing several hundred rivets and other fasteners (see Fig. 29). A fixture was fabricated according to the NADC specification. The specification calls for the beam to be fixed at each end and a hinge fitting installed in the center of the structure where the load is applied. This configuration proved to be very troublesome due to the location of the loading point and the noise generated from it. Because the particular hole expected to crack was the same as that used to pick up the loading point, standard techniques such as waveform and coincidence discrimination or "guard" sensor blocking could not be used. The noise levels encountered were in the range of what is commonly referred to as "white noise", a condition which precludes meaningful AE monitoring. Two box beams were run before abandoning

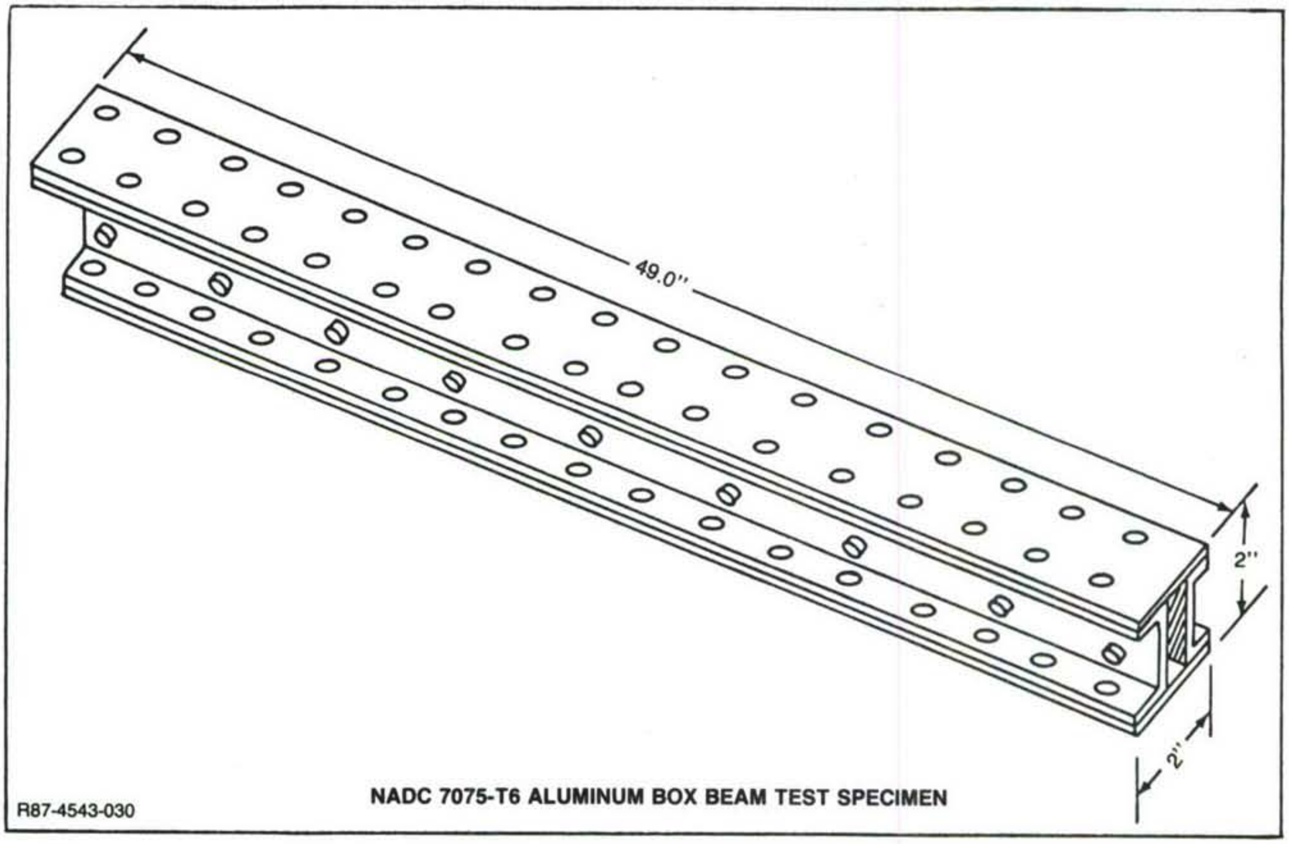

Fig. 29 Box Beam Used in First Series of Tests

the series in favor of a more realistic specimen, (actual structure would have loads distributed over several holes). A summary of the box beam test results follow.

NADC Box Beam Test #1. The first box beam was run on 6/24/85 at 1500 lbs, 2 cps. At 1700 cycles the fixture was redesigned by the addition of a rubber cushion to damp out some of the noise coming from the center hole area. A crack propagated in the center hole to a length of 0.125 in. before it was distinguishable above the background noise. The rise of crack signals above the noise level would have been considered insignificant except for the obvious visual correlation. The crack signals never presented unequivocal evidence of cracking throughout the balance of the test. The specimen failed at 24,000 cycles.

NADC Box Beam Test #2. The second box beam was run on 7/1/85 at 1500 lbs, 2 cps. By 6500 cycles it was apparent that a similar problem of continuous noise existed for this beam also. At approximately 10,600 cycles, signals were appearing in great profusion as baseline noise on the displays. It was attempted to distinguish the signals from the growing crack, but this proved unsuccessful. It was decided to terminate the box beam test in favor of another type of specimen.

3.2.2 Full Scale Bulkhead

The opportunity to monitor a full scale bulkhead became available following the conclusion of the second box beam test. The bulkhead (see Fig. 30) is made from a 6 x 4-ft. 2024-T6 aluminum plate with machined pockets. Central to its design is an arch-shaped cutout which had two radii which were to be spectrum loaded for the fatigue test and monitored by the AEFDSS.

The bulkhead fatigue tests were all performed in the Grumman Structural Test Laboratory where fullscale aircraft structures normally are fatigue tested.

The results of the first bulkhead test was very encouraging since the system did detect the onset of cracking in the bulkhead radius within the time frame predicted by the stress analysis (see Fig. 31 to 34). Figure 30 illustrates the results where left-hand Channels 5 and 6 and right-hand Channels 7 and 8 were predetermined by calibration to be the radius locations. The actual size of the cracks at initiation were not determined since it was required that the test be continued until 2400 Effective Flight Hours (EFH) before shutting down for inspection. At that point the cracks were ~0.1 in. and ~0.125 in. The location accuracy was found to deteriorate as the cracks grew larger.

Four more bulkheads were monitored using the system with similar results. Small crack signals were detected, but the location capability of the system appeared to be quite ineffective.

Analysis of the bulkhead test concluded that on a complex shaped part, such as the centerbody bulkhead, it was not prudent to rely on linear location

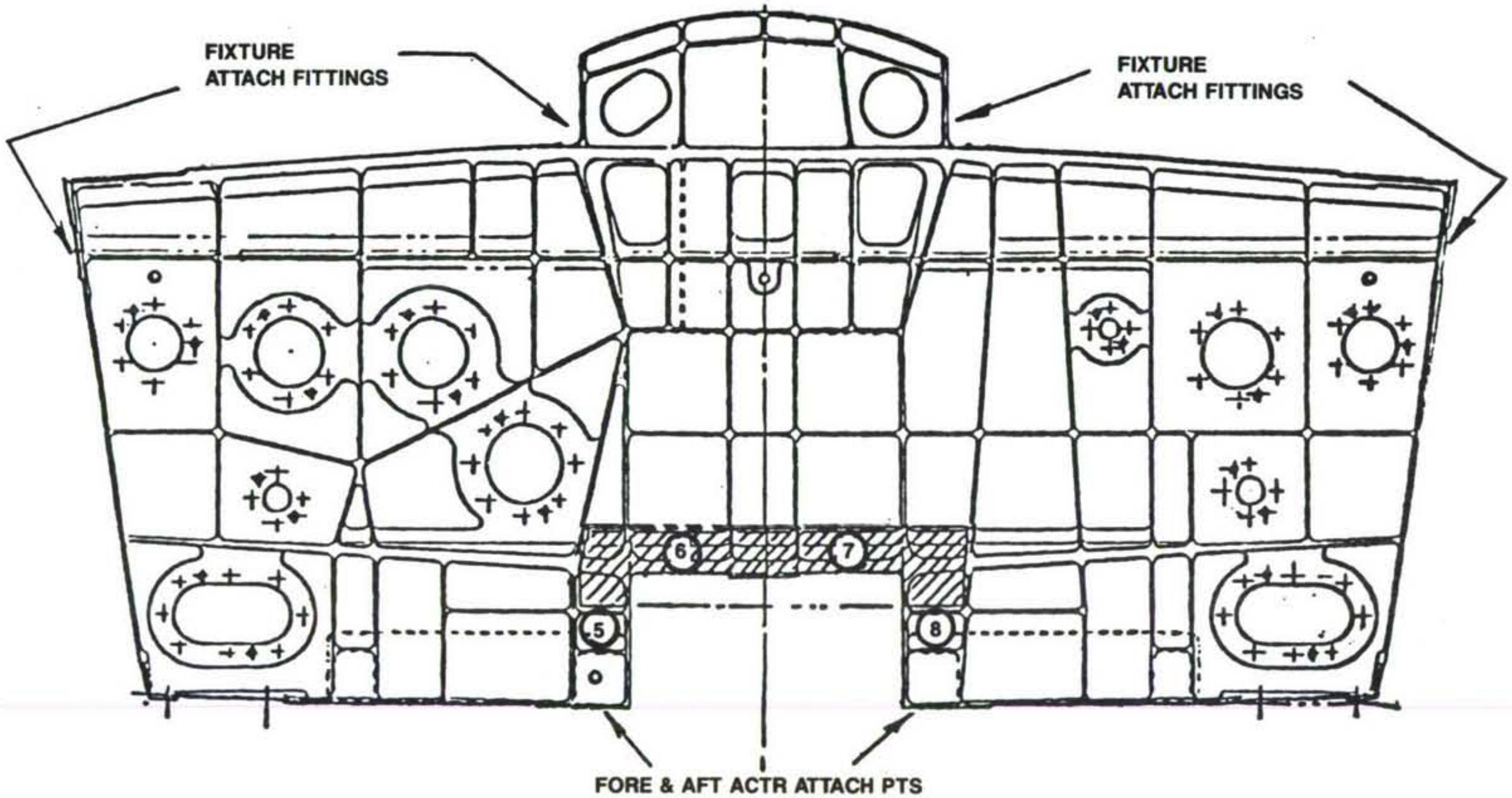

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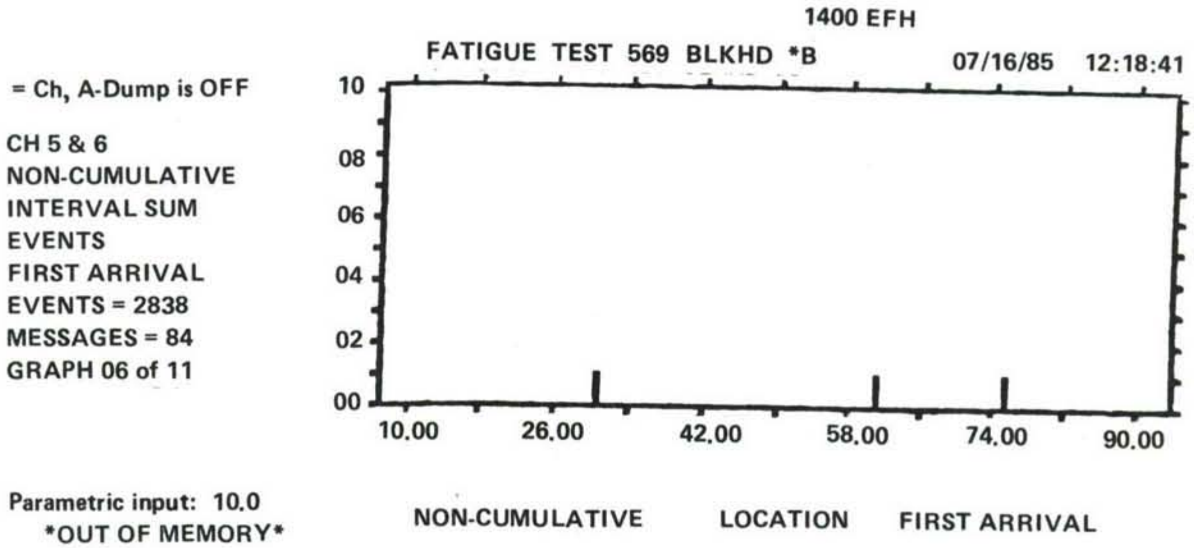
Fig. 30 Bulkhead Specimen Used in Second Series of Tests

as the only source location means. This is due to the strategy employed in linear location; the method of overlapping hyperbola. The weakness of this method is that it is confused by outside signals (with enough amplitude to rise above the threshold) which enter the monitoring zone along the hyperbolic plotting paths, and consequently are incorrectly plotted as valid events.



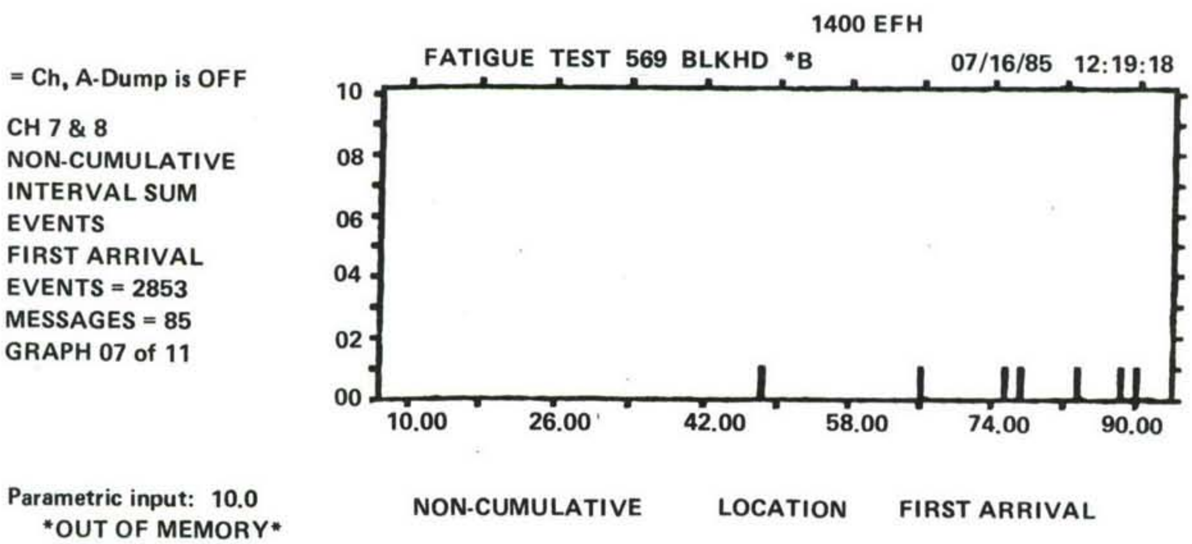


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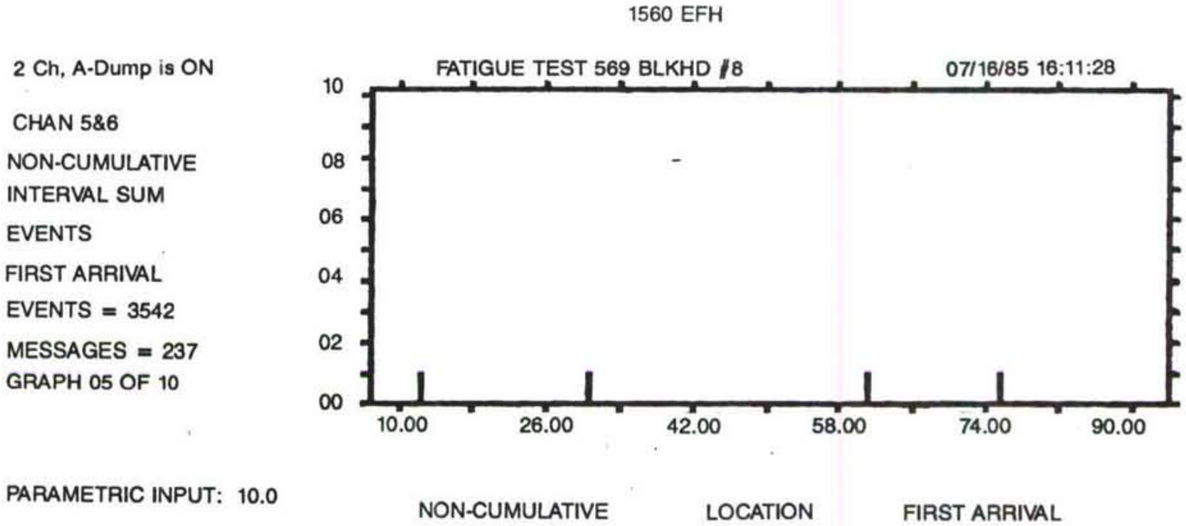
Fig. 31 First Signs of Crack Growth on Both Radii



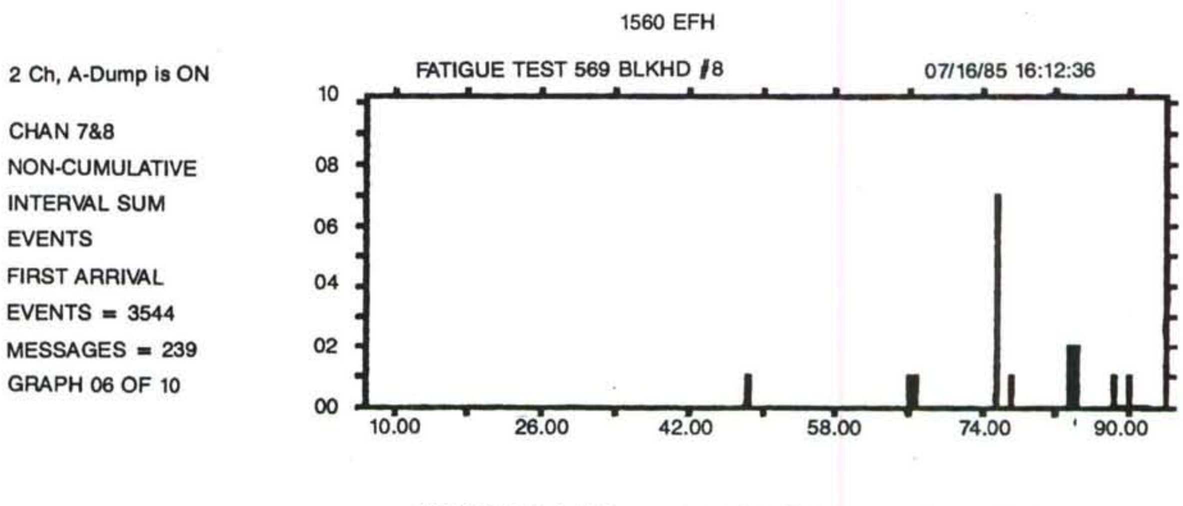


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Fig. 32 Crack on R/H Radius Showing Rapid Growth

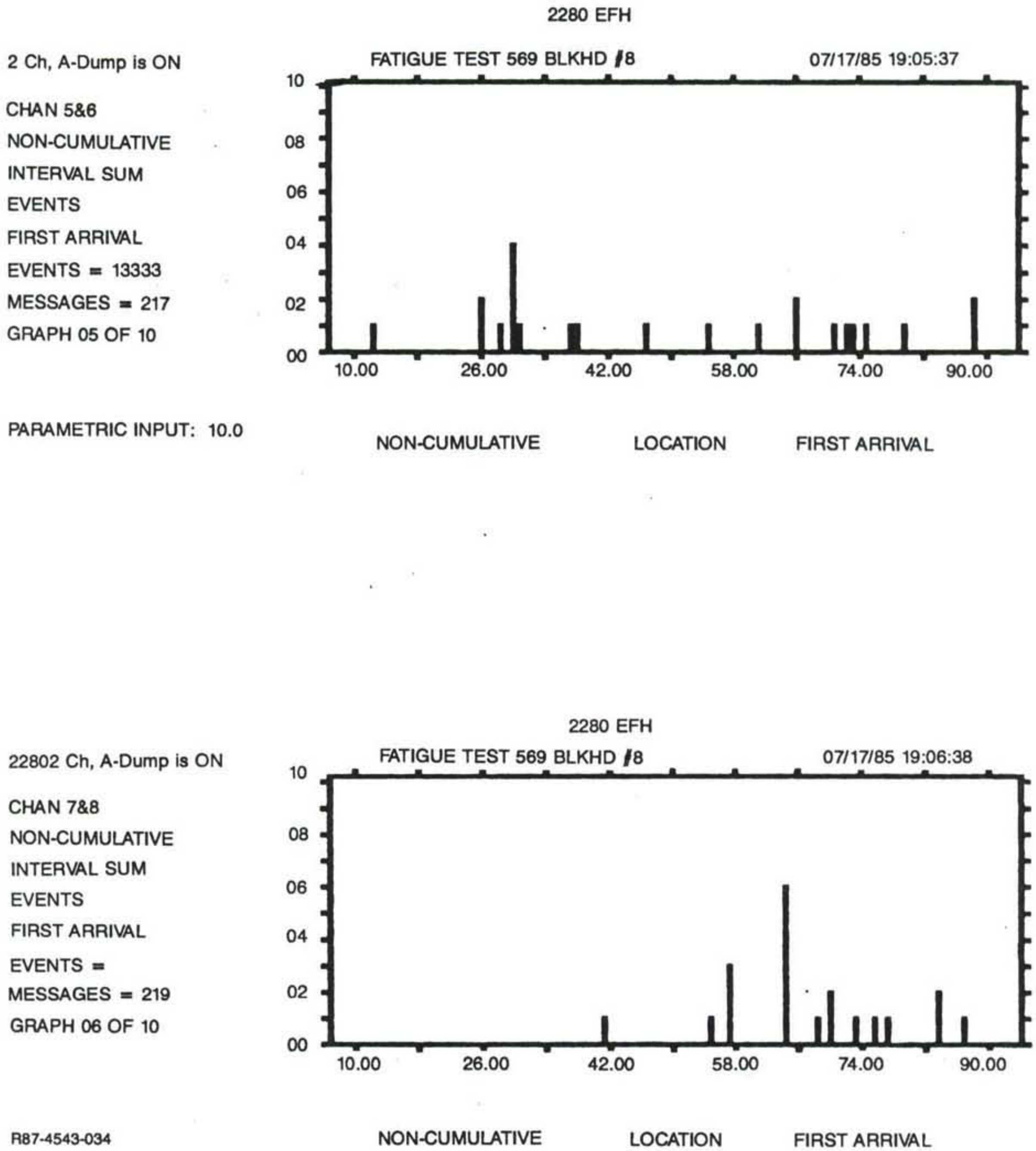
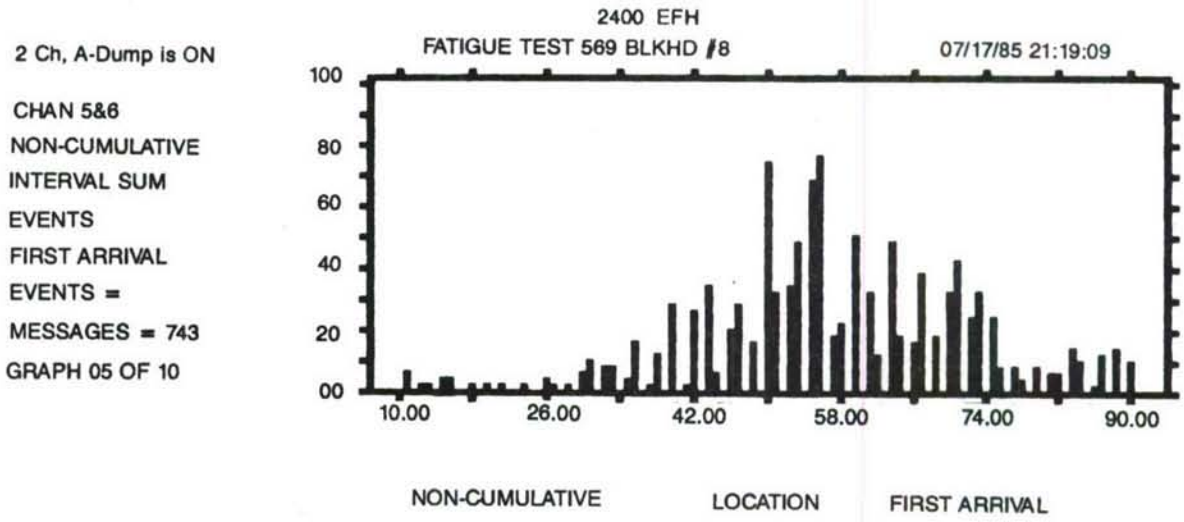


Fig. 33 Crack Growth Activity Shifts to L/H Radius



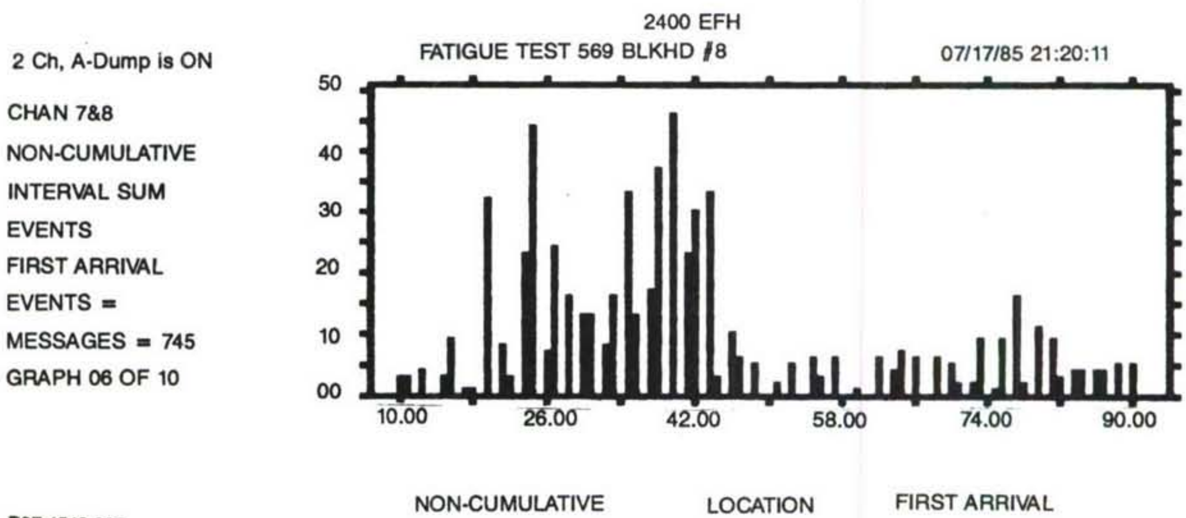


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Fig. 34 Both Radii Showing Rapid Increase in Fatigue Damage

In addition, it was found that the spatial flaw discrimination capability was not totally effective in screening out extraneous signals from known sources, such as loading points. Analyses of the signals revealed that a significant amount of false event locations were displayed, which were caused by concurrent signals from load points outside the area of interest. The signal from one load point would arrive at one sensor and start the timer, and then a signal from another load point would arrive at another sensor and stop the timer. This caused the elapsed time to be less than the anticipated time for a

signal to travel the complete distance between the two sensors, which normally would occur with a single signal originating outside of the two sensors. The end result was false event indications at various locations spanning between the two sensors rather than accumulating signals at the sensor locations.

3.2.3 Description of Required Modifications

3.2.3.1 Two Dimensional Location Capability

Discussions with Physical Acoustics concerning the location errors led to the decision to add two-dimensional location capability. This required some software modifications and the development of special set-up procedures to assure accuracy. The changes were incorporated into the system and functionally checked prior to the final demonstration.

3.2.3.2 Guard Sensors

A system modification to address the extraneous signal discrimination inadequacies was also identified. It involves the use of guard sensors placed near known extraneous signal sources. The strategy of the "guard" sensors is to have means available by which powerful noise entering the monitoring area can be blocked and not included in the data set. They function in the following way; if the "guard" sensors are hit with a signal before a signal is received by the data gathering sensors, a dead time is automatically created for a short period of time, during which their output is disregarded. This strategy assures that a noise signal originating outside of the area of interest will not trigger false signals in the data gathering sensors. The use of "guard" sensors is not applicable when the source of the noise is within the area being monitored.

3.3 FINAL DEMONSTRATION

A series of final demonstration tests were conducted using the fully configured system (see Fig. 35 and 36). The decision to conduct dedicated testing on specially designed test specimens was based on the non-availability of ongoing structural tests and the need for precise correlations. The dedicated test permitted cycle interruptions immediately following first event detection, which enabled initial crack size measurements. The dedicated test also per-

Fig. 35 Fully Configured System Showing Digitizer and Data Acquisition, Computer Display, and Keyboard

Fig. 36 Graphic Display Close-up

mitted the use of starter notches and cycle adjustments to help simulate typical crack propagation conditions.

This test series was conducted on four specimens fabricated to evaluate all the system's capabilities (see Fig. 37). Each specimen is 40 x 10 x 0.125 inch 7075-T6 aluminum. The center of the specimen has two 2-in. dia. holes

NOTE: NOTICE THE FOUR ATTACHED TRANSDUCERS AND THE ACCOMPANYING PREAMPS. A SPECIAL FIXTURE WAS DESIGNED TO SUPPORT EXTRA-WIDE SPECIMENS.

Fig. 37 Two-Hole Specimen Mounted in the MTS Servo-Controlled Fatigue Machine Prior to the Third Test

aligned transversely, one with a starter notch cut with a jewelers file. The extremities of the specimen have four 1/2-in dia holes through which grip-to-specimen attachment bolts are fitted. This area was of some concern before the test began because of its potential as a noise generator. There was noise generated from these areas, but it was successfully filtered by spatial discrimination. The load applied to the specimens was 18 ksi at 1-2 cps, using a 100,000-lb fatigue test machine. The following sections summarize the individual tests that were performed on these specimens using the fully configured system.

Specimen #1. The first test was conducted primarily for calibration purposes to help establish the correct cycle rate and instrument parameters. Initially, the specimen was run at 2 cps (at 18 ksi) which resulted in very rapid critical crack growth (0.40-in. long after 1,000 cycles). The cycle rate was then reduced to 1 cps, but rapid growth still continued since the crack had already reached critical flaw size. Due to the rapid growth rate, there was insufficient time to vary the equipment parameters. It became apparent that these parameters were less than optimum since the crack was first displayed at 1000 cycles when it was 0.400-in. long (see Fig. 38).

Specimen #2. This specimen test was begun with the slower rate of 1 cps at 18 ksi. The system setup file and the program for filtering and discrimination was initially the same as used in Test #1. This particular setup file was suggested by Physical Acoustics as more compatible with the new software than the setup used on the bulkhead tests. The major distinguishing features of the new setup file over the setup file used for the bulkhead tests were; longer sampling rate, shorter rise-time time out, and shorter single-channel event time-out (see Fig. 39).

The test ran until 2100 cycles, at which time a crack was first noted. At this time the crack appeared to be about 0.030-in. long. No data plots were made by the AEFDSS, however, and the test was allowed to continue until the crack propagated to about 0.045 in. It was noticed that a large volume of signals was being detected, but none were plotted. It was decided to stop the test and change the setup file to the one used for the bulkhead tests.

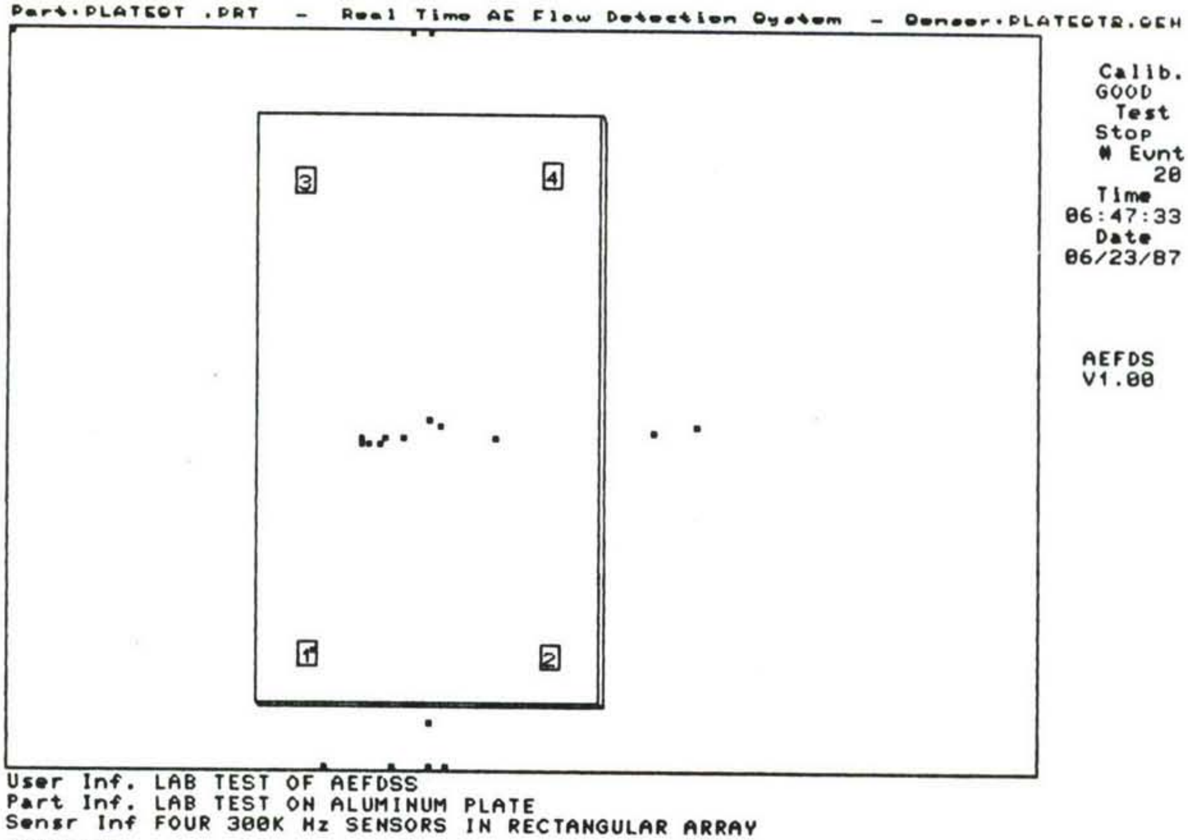

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Fig. 38 Printout of Graphics Display Showing Cluster of Plots Near Cracking Hole of the Specimen

The test was resumed with the new setup file, and data was immediately plotted correctly on the display. At this time the crack was 0.050-in. long. The crack was allowed to grow to 0.250 in. before the test was stopped at 3700 cycles. Before the test was stopped the AEFDSS continued to perform properly, plotting only data from the hole area, at a rate consistent with the crack growth (see Fig. 40).

<u>Specimen #3</u>. This test was run with the same system parameters as Test #2; 1 cps, 18 ksi, and the bulkhead setup file.

At 1200 cycles into the test, the first plot of a crack signal was made, although no crack was evident visually. Between 1200 cycles and 2500 cycles four more individual plots were made around the hole area, clearly indicative of crack propagation activity. A visual inspection made at 2500 cycles detect-

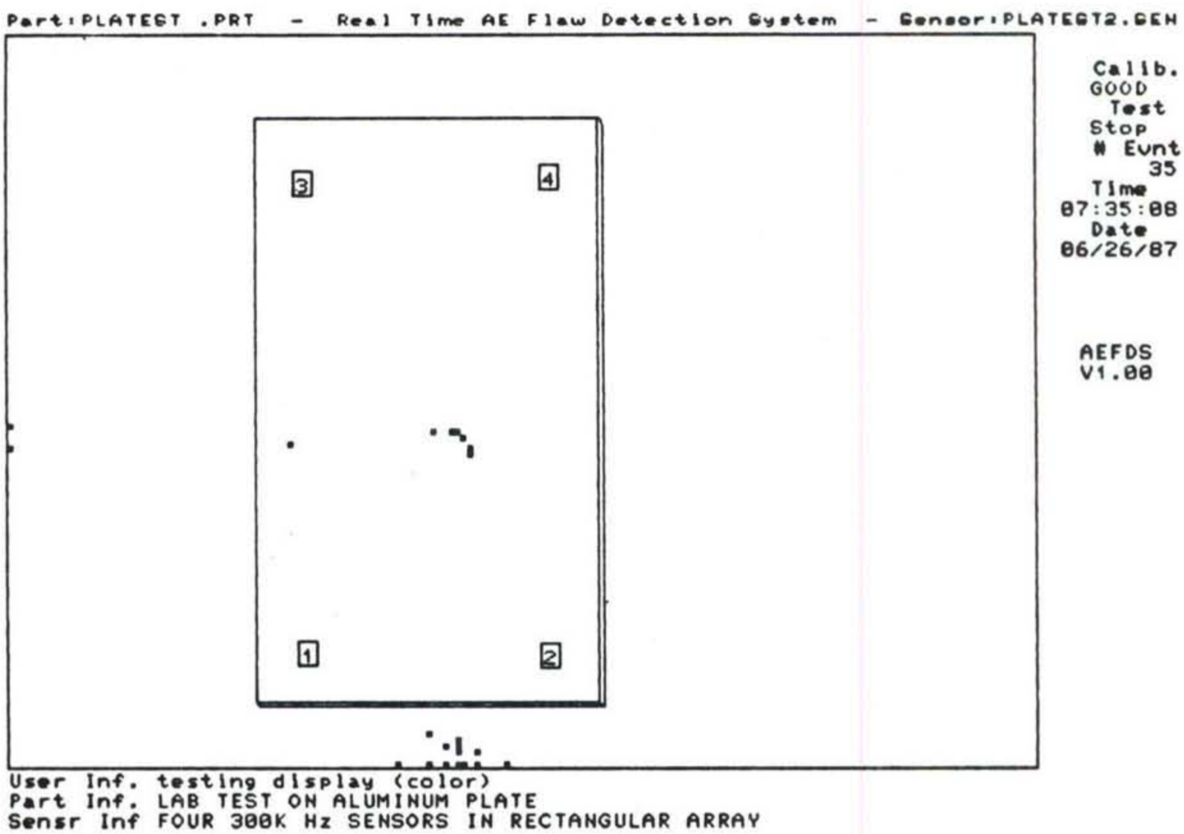
```
FILE:  A:SETUP.488            TOTAL GROUPS =  1              [1] GROUP #  1
[2]  1 PARAMETRIC(S)  PID(S) 1                               [3] SAMPLING  10000  ms
[4] 12 CHANNEL(S)     CID(S) 1-12
[5] SYSTEM PARAMETERS         [6] A / [7] F  PARA.   TYPE        LOW        HIGH
=======================       ======================================================
GAIN                30 dB     FILTER         DUR.    SCSH         20        2000
RTTO               100 us
SCETO              100 us
THRESHOLD           45 dB
REARM TIME        1000 us

[8] TIME DRIVEN DATA SET                                     [9] HIT DATA SET
========================                                     ===================
RATE             60000  ms                                   COUNTS, DURATION
PARAMETRIC(S)    1                                           ENERGY, AMPLITUDE
AE CHAR.                                                     RISE TIME
```

R87-4543-038

NOTE: EACH ATTRIBUTE IS KEY-ENTERED AND SAVED ON DISK TO SAVE SETUP TIME.

Fig. 39 Printout Showing the Program or Setup File Created to Filter and Discriminate the Signals Received During AE Monitoring



NOTE: EXTRANEOUS PLOTS ARE A RESULT OF SENSITIVITY CALIBRATIONS PERFORMED DURING THE TEST.

R87-4543-039

Fig. 40 Fatigue Damage (Crack) Plotted Near Hole

ed the presence of a 0.030-in. long crack in the notch of the specimen. The test was stopped at 2800 cycles, leaving a crack 0.060-in. long exiting the hole (see Fig. 41).

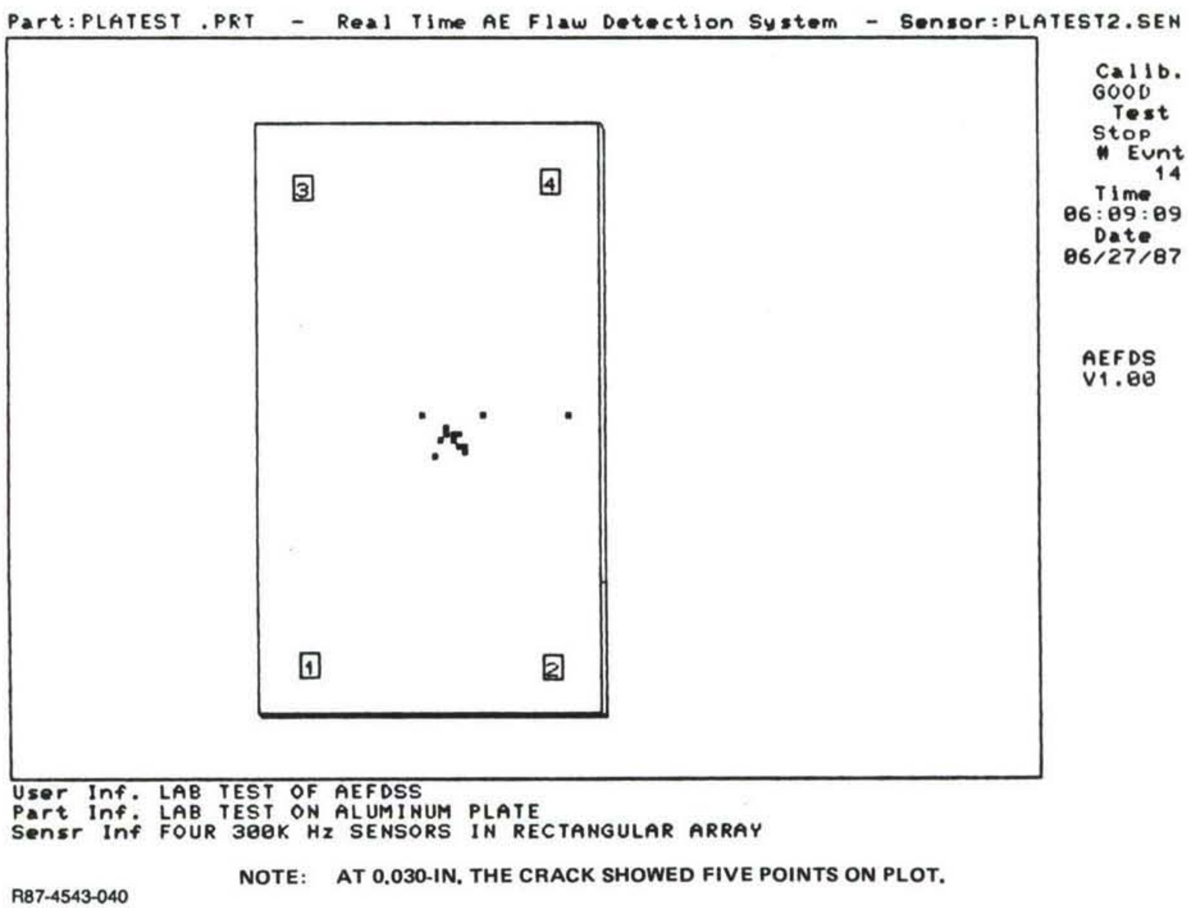


Fig. 41 Plots Obtained From 0.060-in. Crack

Specimen #4. The final test performed used the same parameters as Tests #2 and #3.

Crack signals were plotted at 1400 cycles and continued until, at 2100 cycles, a 0.050-in. crack was visually detected. The number of events plotted in this test were several times the number plotted previously. The volume of signals processed during this test run appears to correlate to the high crack propagation rate which was occurring. The test ran at a relatively fast pace until it was stopped at 3200 cycles. The crack had extended to 0.280 in. by the end of the test (see Fig. 42).

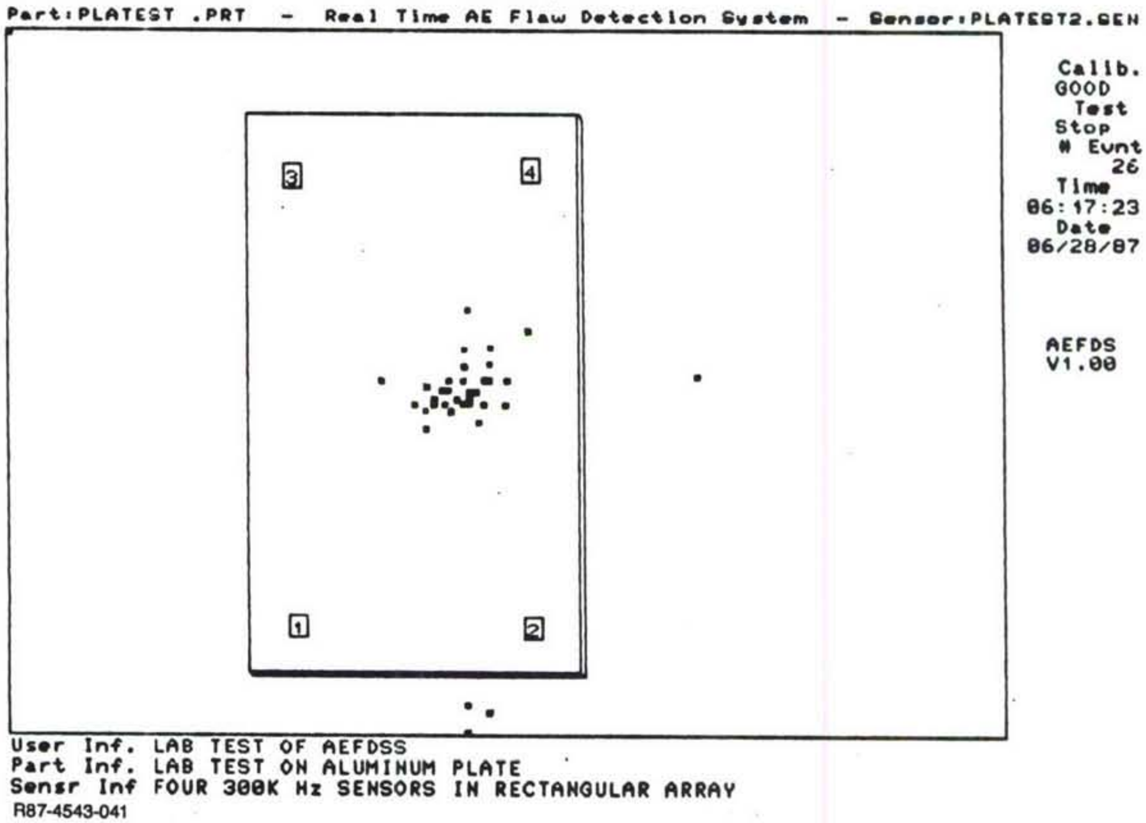


Fig. 42 Printout Containing Large Number of Plots Correlating to the Rapid Growth of the Crack

4 - CONCLUSIONS

- An Automated Early Fatigue Damage Sensing System has been developed which has demonstrated the capability of detecting 0.050-in. long cracks propagating during low-cycle fatigue structural testing.
- The system has demonstrated the capability to input the part profile and sensor locations and output the crack signal location on a graphic display of the part outline and sensor locations.
- The system has demonstrated the ability to discriminate extraneous signals from true crack signals using wave form, spatial, and "guard" concepts.

5 - RECOMMENDATIONS

- The delivered system should be considered for immediate AFFDL fatigue test monitoring applications involving structures similar in size to the bulkhead that was evaluated (approx 24 sq ft).
- An expansion of the system should be considered for larger applications. The existing chassis can accommodate 26 more channels for a total of 40 channels. Additional copies of a full 40 channel system could be linked to common input & output devices for very large applications, such as a full scale aircraft.
- The digitizer to graphics software should be considered for future modification to enable the digitizer stylus to be lifted from the tablet to draw unconnected lines. This would permit other shapes within the part outline to be displayed without connecting lines.
- The graphics display software should be considered for future modifications to provide varied color assignments to event locations depending on their accumulation. This would permit further discrimination of meaningful events based on the rate of activity at a specific location.

APPENDIX

AUTOMATED EARLY FATIGUE DAMAGE SENSING SYSTEM

- SYSTEM DESCRIPTION
- SOFTWARE DOCUMENTATION
- OPERATING MANUAL

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LIST OF ILLUSTRATIONS

1 - INTRODUCTION

1.1 OVERVIEW

The AE (sub) system of the Grumman AEFDS System consists of a standard Physical Acoustics Corporation (PAC) SPARTAN system, a high resolution color CRT, a graphics board, and digitizer tablet. The special software supplied with this standard hardware allows the use of the system as a real time flaw location system showing the part under test, sensor position, and location of stress release.

Material under stress rearranges itself to accommodate the stress. This change of structure causes energy to be transmitted away from the stress release point by elastic vibrations of the material. Piezoelectric sensors detect these waves and generate signals into digital information, which is recorded on magnetic storage media in the PAC 3000 computer system. Part of the data recorded is a very accurate time of detection of the start of the signal. Since the effective wave velocity of all detected sources is essentially constant, the origin of a wave can be determined from the time differences of the hits and the sensor locations of those hits.

The special software provides the user three distinct parts needed to do the fatigue test and display. The first part is the ability to transform a part outline into a file containing the information, and the ability to display the outline on the high resolution CRT during the test. The digitzer provides the means to enter the information in a convenient manner. The second part allows for the overlay of sensor information on the display of a part. This information may be written to or read from a file. The graphics initialization for a test is an independent program. The third part of the software is a modified version of the SPP/DAQ series of data acquisition software. The modifications are added subroutines which send data acquisition commands and location data to the graphics board during data acquisition replay of the test data. This special software also has the ability to command the graphics board to copy the CRT display on the printer.

1.2 HARDWARE DESCRIPTION

1.2.1 Major Components

1.2.1.1 SPARTAN Data Acquisition System

System Components. The data acquisition component of the AEFDSS is a modified 12 channel SPARTAN/3000. The basic SPARTAN system is divided into two cabinets housing equipment which serve two general functions, those of data acquisition and those of data storage/display.

The two major system components, the data acquisition and display, are supported by several additional sub-systems including: transducers and preamplifiers, connecting cables, graphics interface board, color monitor, digitizer, and "guard" sensor circuit boards. In addition, special software to integrate the various functions is also included.

The Grumman modifications to the SPARTAN system are add-on components which leave the basic SPARTAN intact. This was done to reduce cost of development and to allow servicing of the system by the vendor's field engineers.

The following components comprise the system:

Transducers & Preamps. The Automated Early Fatigue Damage Sensing System uses 3/8-in. dia, 300-kHz piezoelectric transducers to convert the stress waves propagating in the test article into electrical signals. Coupling the transducers to the part can be accomplished by either use of gel or cyanoacrylate glue. The signals are transmitted from the transducer through microdot connectors and cable.

Each transducer sends the raw signal to an individual preamplifier which contains a 200- to 400-kHz bandpass filter. The filtered signal is then sent to the data acquisition part of the SPARTAN for further processing.

It should be noted that sensors of any frequency can be used with the system as long as the appropriate matching filters are provided in the preamps and on the channel boards.

Data Acquisition. The signal entering the data acquisition system passes through an envelope filter on the channel board of the SPARTAN which also has a filter tuned to the 200 to 400-kHz band. The data acquisition system can be programmed to filter the signal according to user selected discrimination variables. The software filters of the data acquisition system can create discrimination variables for the signal according to rise time, ringdown counts, duration, energy, amplitude and location.

After this preconditioning, the signal is held in the processor buffer until it can be forwarded to the display system. The buffer can hold 8k bytes of data before it overflows. The time that is required to dump the other five channel board buffers is much less than the time that most incoming data could fill any one buffer, so that a very large part of all the raw data is eventually collected.

Color Monitor and Graphics Interface Board. Provided as part of the system is a 13-in high-resolution color video monitor capable of displaying data which could not otherwise be displayed on the resident monitor that comes as part of the SPARTAN system. It is connected to the AEFDS system through a 9-pin "D" connector into the backpanel of the 3000 display cabinet.

Control of the color monitor is accomplished through the use of an interface board specially designed for this application. The board is permanently installed in the cabinet of the 3000 display. A cable connects the board to the color monitor through the 9-pin connector. The color graphics interface board provides the color monitor with a 640 x 408 pixel screen for high resolution presentations.

The high-resolution color graphics interface board also enables calibrations made with the SPARTAN/3000 to be used in plotting the AE data inside the part outline according to the transducer placement. Without this coordination the data could not be transferred between the 3000

and color monitor. Special software mentioned below allows the programming that sets up this graphics board interface link.

Digitizer. The AEFDSS has a ditgitizer tablet which is used to change a drawing of the part under test into a digitized code that enables it to be displayed on the color monitor. The digitizer is 16 x 16 in. in size and is connected to the 3000 computer through a RS-232 connector. The digital coding of the part is accomplished through the use of a stylus which is connected to the tablet through its own connector.

Software. Software programs have been developed which set the format for digitizing pictures and sensor placement, and coordinating them with the data from the AEFDSS data acquisition system.

The software provides the three phases necessary to conduct a test on a fatigue specimen. In the first phase, the software coordinates the digitizing of the part outline into a file which can be stored and retrieved. This coordination involves the digitizer, the graphics interface board, the disk operating system, and loading the color board initialization program.

The second phase involves the placement of the transducers on the part outline. The data acquisition system is presently capable of handling twelve data gathering and two "guard" sensors which can be readily displayed in their appropriate place on the outline, as they will appear on the actual part. But the software can display many more transducers than the data acquisition system can handle, so that the software can cover a system expansion with no modification up to 128 channels.

The third phase accounts for the calibration of the system, and is a version of the SPP/DAQ series of programs. This version is written as a subroutine and actually coordinates the data acquisition commands and location data with the graphics board and the replay of recorded tests. An additional function of the software involves the output of data to a color line printer, which is an optional accessory.

1.2.1.2 The High Resolution Graphics Board

This is the intelligent graphics processor and CRT display controller. The board is capable of high resolution (640 x 408) display in eight colors or gray scale monochrome graphics. Down loaded software may be used to generate displays from AE data. Auxiliary devices can be attached to either of the two serial input/output ports for direct communication with the graphics processor.

1.2.1.3 The Digitizer Tablet

This is a device which consists of a stylus, a tablet, and an accurate sensing system. The position of the stylus can be sensed by the tablet and sent in to the graphics board when it is requested by subroutines.

1.2.2 <u>Specifications</u>

Each of these hardware devices has its own manual containing physical and electrical specifications. For details refer to these manuals.

- SPARTAN
- High Resolution Graphics Board/Digitizer

1.3 SYSTEM SETUP

1.3.1 <u>SPARTAN</u>

This information is included in the SPARTAN manual.

1.3.2 <u>High Resolution Graphics Board</u>

This is a PAC installed device, and there are no adjustments that the user can make without special test equipment. The external connections are described in Subsection 1.3.4. Should the need arise to remove any cable, refer to this Subsection. Ribbon cable wires 1,5,10,15... are colored. Inspection of the cable will allow for the determination of the location of the end of the plastic connector containing pin 1. The circuit board has numbers for pins near all the connectors. Turn the connector so that the ends are in the proper orientation and press it into the pins while making sure that all the pins enter the plastic socket.

1.3.3 Digitizer Tablet

The tablet is Original Equipment Manufacturer (OEM) equipment. It has three switches which control its operation, which are correctly set and should not be changed. Refer to the separate manual for instructions on how to connect the parts. To connect the tablet to the 3000, select a serial (printer) cable with a "D" connector. Put one end into the rear of the digitizer and the other into the plug on the rear of the 3000 with the label, "Tablet". The bottom of the digitizer has openings which allow access to 3 "dip" switches. They were set at the factory before shipping. DO NOT change them.

1.3.4 Color CRT

This OEM equipment also has its own manual. However, connection is made using a 9 pin "D" connector from the monitor to the rear panel of the 3000. Either end of the cable may be plugged into the CRT. Insert power cord and turn on the CRT using the pull switch in the front.

1.4 INITIAL SYSTEM TESTING

With exceptions mentioned in the paragraph below, all three of these procedures are the same as those in the SPARTAN software manual:

- Booting The System
- Backup of Software Diskettes
- SPARTAN and GRP/DAQ Test Procedures.

Test Color Graphics. The system disks are configured to automatically run the color graphics program. If it doesn't happen, it will have to be run manually, (see Subsection 2.3) and PAC should be informed about the problem later. If the color graphics startup program doesn't return to the >A (called "A" prompt) then the color graphics board has hardware problems. When the program has finished, the initial display should be shown on the color CRT. If not, it must be made sure that the CRT is connected and that the power is on (increase brightness to max). If some streaks of color appear, the CRT should be adjusted using the adjustments on the front panel. If no color appears, check the installation of the color board before calling the factory.

If the display is normal, then run the program GRUSER and select Option 5, which will cause the color board to print a copy of the screen. Should the printer fail, check its installation before calling the factory.

2 - SOFTWARE COMPONENT DESCRIPTIONS FOR GRUMMAN SPECIFICATIONS

2.1 INTRODUCTION

2.1.1 Preface

This section of the manual describes only the software specific to the Grumman Part Location System and the data acquisition software modifications specific to that system. The only standard SPARTAN software mentioned here is the location group setup and calibration procedures. If not familiar with the SP/DAQ program series, it may be desirable to review the program menus and repeat the system checkout procedure in order to become familiar with the program.

2.1.2 General Description of the Software

The high resolution color graphics board has a start up program which initializes the board when the power is turned on. The software for the plotting is to be loaded into RAM memory and executed by the start up program. The user will have to run a start up program on the 3000 (GRDL) which actually tells the graphics board program to receive, load, and execute a program, which is stored in a disk file. If the color display has warmed up and is blank, the program should be down loaded using the GRDL program.

The part descriptions are files on a disk which consist of the results of a part outline definition and a part name-number entry. The program GRUSER can read or write these files, and communicate with the graphics program in the color board to allow the user to see, alter, or make a part definition on the screen and save it in a file, if desired. (This program requires the digitizer).

The user can also read and write, and cause it to be the sensor position information file using the sensor placement option. Finally, a calibration file can be sent to the color board so test locations can be displayed.

2.2 STEP BY STEP PROCEDURE FOR A COMPLETELY NEW PART

1. Make sure color display board is running.
2. Use GRUSER to make the part definition file.
3. Mount the part and sensors.
4. Run SPP/DAQ and define the part location group(s).
5. Do a delta T calibration run for all the sensors, and set the delta T calibrations as needed for all the groups.
6. Use the system setup option, "Save Graph INI File", to write your program set up information to the disk.
7. Take a short test and save the data. This "calibration" file now has the required geometry information and is now ready to do the sensor placement. Exit SPP/DAQ.
8. Run GRUSER.
9. Read the part file.
10. Measure the sensor placements and enter the positions using the sensor placement function.
11. Save the position file.
12. Read the position file.
13. Do the pretest graphics board initialization using the information in the calibration file.
14. Exit the program.
15. Run GRP/DAQ.
16. Use the system setup option, "Load Graph INI File" to read in the data acquisition program's timing information.
17. Do the test (save the data).

The test may be repeated as often as desired until either the system power goes off, or a new part, placement, or calibration is needed. To restart from no power, complete Steps 1, 8, 9, 12, 13, 14, 15, and 16. It is then ready to do another test on that part.

This procedure saves the pretest auxiliary information in four files:

- A part outline file [.PRT]
- A sensor placement file, specific to the first file [.SEN]
- A calibration file for a specific pair of the first two files [.DTA]
- A file, corresponding to the calibration in the third file which is used by the data acquisition program [.INI]

2.3 STARTING THE AEFDS SYSTEM

The program is stored in a disk file with the extension of "BIN". PAC configures the CP/M (R) disk operating system to automatically do such initialization the first time the system is loaded into the computer. If the GRDL program is run, the program will indicate what file it is loading or cannot find. If it is not known how to "run a program", go back to the initial system testing section. The program will look for specific files ending in the extension ".BIN". If the disk doesn't have these or the GRDL program, they should be copied from the archived master disk.

GRDL can be run only one time after the system is reset. If any of the special programs fail, press front panel START and RESET buttons simultaneously, which resets the whole system. GRDL can now be run again.

2.4 OPERATION OF THE USER INTERFACE PROGRAM (GRUSER)

2.4.1 Introduction

This program provides an interface for sending commands and (non-AE) data between the 3000 computer and the color graphics software. The end user will get a modified version with the ability to read pre-recorded part and sensor files and send the data to the color board for display. It will also read AE calibration information from an ordinary data file and send it to the program in the color board. The ability to read and send these three types of files is needed to do an AE location test with the locations shown on the color CRT.

The current program provides the user with the additional capabilities needed to create the special part outline and sensor placement files while interactively using the color options and the digitizer tablet.

2.4.2 User Interface Program (GRUSER)

The purpose of this program is to provide the user the means to interact with either CPU as needed to build the part outline and sensor placement files, and to provide the means to initialize the color board for test location graphics. The current version of the user interface program sign-on message is shown in Figure A-1.

```
 Automated Early Fatigue Damage Sensing System
Version 1.00    [Dec. 21, 1986]
Copyright 1986 by Physical Acoustics Corp.
```

R87-4543-042

Fig. A-1 GRUSER Sign-On

The user entries try to be as consistent as possible. Numerical input for options or channel numbers will treat a negative number as an abort request. The numeric value shown in brackets will be kept if just the return is pressed. If a bad number is entered, a message is typed and the program retries numeric input. If a yes or no response is requested, the program shows a Y or N as the default value to be selected if the return key only is pressed. (Only the first character of the string is checked).

2.4.2.1 GRUSER Main Menu Options (See Fig. A-2)

Part Definition Options. See Subsection 2.4.3.

Sensor Placement Options. See Subsection 2.4.4.

Test Setup Options. This option will become a stand alone program for the end user (See Subsection 2.4.5).

Exit Program. This option returns to the disk operating system.

Screen Copy. This option will cause a copy of the screen to be printed on the printer attached to the rear panel of the 3000 Display.

```
MAIN MENU

1)   Part Definition Options
2)   Sensor Placement Options
3)   Test Setup Options
4)   Exit Program
5)   Screen Copy

Please enter your selection
Now = 1 [<CRLF> gives no change] Enter new 1
```

R87-4543-043

Fig. A-2 GRUSER Main Menu

Make sure that the printer is on, connected, and selected before questioning whether or not this option is functioning. Figure A-3 shows the actual output when Options 4 and 5 are selected.

```
MAIN MENU

<:
5)   Screen Copy

Please enter your selection
Now =  3[<CRLF> gives no change] Enter new 5

Make sure the printer is ON


MAIN MENU

<:
4)   Exit Program
<:

Please enter your selection
Now =   5[<CRLF> gives no change] Enter new 4

Please confirm that you wish to quit
Default for <CR> is Y

STOP

A>
```

R87-4543-044

Fig. A-3 Example Hardware Copy

2.4.2.2 File Selection Subroutine

File operations are invoked by Options 5 and 6 in Fig. A-7, 5 and 6 in Fig. A-8, and Option 2 in Fig. A-9 as a common subroutine.

When selected, this subroutine will allow a chance to exit the automatic selection of Options 2 and 3 after having been shown the present drive: filename. type file description. If unsure whether or not the requested file is available, the best procedure is to answer "N" and go immediately to the menu. Option 1 will show whether or not the file exists. An example of this is shown in Fig. A-4, where the default part file is shown and an immediate exit to the menu is selected by the "N" at the end of the third line.

```
A:PARTOOOO.PRT
Do you want to change the Drive:File?
Default for <CR> is Y N

1)  Do a directory of current drive
2)  Change the current drive
3)  Select the file
4)  File O.K. Exit and KEEP
5)  QUIT    DON'T KEEP FILE
Please enter your selection
Now =   1 [<CRLF>] gives no change] Enter new 2

Drive now [A] set to letter A, B, ...C

Drive set to C:
```

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Fig. A-4 File Selection Menu

Do a directory of the current drive. Shows all the files on the drive shown just above the menu. (Fig. A-5 has "C" drive selected whereas Fig. A-4 has "A" drive selected. Only 2 files were found).

Change the current drive. This allows changes of the current drive. The default value is shown inside of a "[" and "]". Figure A-4 shows a change from "A" to "C" drive, which is a hard disk.

Select the file. This option lets the user change the name of the file but not the type. The procedure depends on whether a read or write was re-

quested. If a "read" of a file was requested, the number of the file must be entered as shown by the directory option. When a "write" of a file is requested, the file name must be entered. The status is checked after the file is selected. Figure A-5 shows the result of a directory and Fig. A-6 shows the selection of the first file (PART0000.PRT) in the list. (The program declared the file as good by showing O.K. because the file was found. The user must make sure that the length is greater than zero).

```
File selection options
C:PART0000.PRT

1)   Do a directory of current drive
2)   Change the current drive
3)   Select the file
4)  File O.K. Exit and KEEP
Please enter your selection
Now =    2 [<CRLF> gives no change] Enter new 1

1)  PART0000.PRT       2)   PART000X.PRT
```

R87-4543-046

Fig. A-5 Directory Example

```
File selection options
C:PART0000.PRT

1)  Do a directory of current drive
2)  Change the current drive
3)  Select the file
4)  File O.K. Exit and KEEP
5)  QUIT     DON'T KEEP FILE
Please enter your selection
Now +    2[<CRLF> gives no change]  Enter new 3

From the list, select the file [-1 to quit]
Enter the number of the file you want
Now =    1[<CRLF> gives no change] Enter new 1

Checking the file status - Please wait for menu
Looking for file
C:PART0000.PRT
-------------
Size =  9Kbytes
O.K.
```

R87-4543-047

Fig. A-6 Access of an Existing File

File O.K. Exit and KEEP. If the file status is "O.K.", the read or write will proceed normally. If the status hasn't been checked, it will do so at this time.

QUIT - DON'T KEEP FILE. No read or write will be done, this option just returns to the previous menu.

2.4.3 Part Definition Options

The choices are listed in Fig. A-7. The general purpose of this option is to be able to trace a part from a drawing and have that outline displayed on the screen. The steps needed to display a new outline are:

- Clear any old data or rescale the tablet
- Trace the outline (Option 2) until the desired shape is attained
- "Save" the screen in a disk file.

```
Part Outline Options

1)  Clear outline
2)  Draw outline
3)  Erase last point/line of outline
4)  Rescale the tablet to a new drawing size
5)  Read an outline file and show on screen
6)  Save the outline in a file
7)  Redraw the screen [No change of data]
8)  Exit from this menu
Please enter your selection
Now =   1 [<CRLF> gives no change]  Enter new 8
```

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Fig. A-7 Part Outline Menu

Clear Outline. Removes all the points on the screen (and all sensors also - Subsection 2.2.4.4).

Draw Outline. The user places the stylus on the first point of the outline and traces the drawing until the figure is finished. The program draws from point to point when the stylus has moved at least 0.025 in. The user can generate a straight line if the stylus is picked up and moved to the end of the line. Otherwise the stylus must be kept pressed down or the points will not register.

Erase Last Point/Line of Outline. This removes the points, from the end, until Option 2 is selected again. After selecting this option, the stylus can also be used to remove points. Each "beep" from the tablet is the signal that the program is removing another point from the outline.

Rescale the Tablet to a New Drawing Size. When this option is selected, place the drawing approximately in the center of the tablet (and secure it). Press the stylus once on the lower left hand corner of the region of interest and once on the upper right hand corner. This will rescale the tablet area bounded by these points to fill the bordered area of the color CRT. When this happens, all data on the screen is reinitialized.

Read an Outline File and Show on Screen. Allows the user to select a part file for display on the CRT. All old information is lost if a file transfer is started.

Save the Outline in a File. Saves the outline as shown on the screen in the file selected by the user.

Redraw the Screen [No Change of Data]. For the user's convenience only.

Exit From This Menu. Returns to the main menu.

2.4.4 Sensor Placement Options

Before anything useful happens, there must be a part outline on the screen and a file name in the upper left hand corner. If the user has just entered on via the tablet and saved it, the file must be re-read using the part menu so that the name appears on the screen. If the user proceeds to put the sensors on a part and then save the results in a sensor file, the part file name is also saved. When a sensor file is read into the color board, that part file name is checked against the current name. They must be the same in order to proceed.

The sensor placement options are shown in Fig. A-8. The last four are "identical" to the last four options for the part outline menu of Fig. A-7. The only difference is that the file type is not the same, and the program processes the files according to the file type.

```
Sensor Options

1)  Clear all sensors
2)  Put one (s) sensor on part
3)  Remove a sensor from part
4)  Put a series of sensors on the part
5)  Read sensor file and show on screen
6)  Save the sensor information in a file
7)  Redraw the screen [No change of data]
8)  Exit from this menu
Please enter your selection
Now =     1  [<CRLF> gives no change] ENTER NEW 8
```

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Fig. A-8 Sensor Menu

Clear All Sensors. Go to a clean slate to make a new sensor arrangement.

Put one (S) Sensor on Part. When the user selects this option, a channel number will be asked for. Once that number is entered, the command is sent to the color board, but the 3000 shows the sensor menu. If the tablet is not used to place a sensor before selecting another option, this command will be ignored.

To place a sensor with the tablet, place the stylus on the tablet and press it down. The sensor will appear on the screen (if the stylus is inside the drawing area) in a trial position. If in the correct place, press the stylus again in the same place to fix the location. If it is not in the correct spot, move toward the correct spot and press down again. The sensor will move to the new "trial" portion. When the current sensor is fixed, another may be positioned.

Remove a Sensor from Part. Selection of this option will request a channel number. If the channel entered is on the screen, it will be erased

from the list. This erasure can clear other lines on the screen. Option Number 7 will redraw all existing information.

Put a Series of Sensors on the Part. Selection of this option allows the user to enter the total number of sensors and the individual channel numbers without returning to the sensor menu each time, as would be done if Option 1 was used repeatedly.

Options 5 through 8 behave as in Subsection 2.4.3, except that the file type is .SEN instead of .PRT.

2.4.5 Test Setup (Calibration File Options)

Figure A-9 shows the menu the user will arrive at when either the part or sensor file is invalid. If the user has sent both of these successfully, but cannot send the calibration information, then a third option will appear so that another try could be made without having to resend the part and sensor files.

```
CALIBRATION FILE OPTIONS
 -- WATCH THIS ONE -- Exit option is first

1)  Exit
2)  New Setup
Please enter your selection
Now =     1 [<CRLF> gives no change] Enter new ?
```

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Fig. A-9 Calibration Menu

Exit. Returns the user to the main menu.

New Setup. This option asks the user to select and send (in order) the part file, the sensor file, and the calibration file. If either of the first two file transfers fails, the program returns immediately to the menu.

NOTE: If the part file is already valid (on the screen) and the user wishes to keep it, file select Option #5 may be chosen (see Fig. A-4

for example). This will cause the program to skip the file transfer, but this option will go on to download the sensor file since the part file is valid.

2.5 DATA ACQUISITION AND REPLAY SOFTWARE (GRP/DAQ)

2.5.1 Location Data Acquisition Software

The SPARTAN planar location software can do planar and linear location simultaneously during a test. The special SPARTAN program can handle five different types of location, but the graphics board will display data only for three types of location (Linear, F-placement, and Rectangular). The location groups can include multiple contiguous sensor arrays of a location type, and these may be wrapped (around on a cylinder). The specifics of the setup are described in the SPARTAN Software Manual.

The color graphics location program can map any sensor pair calibration onto the screen if the sensors are part of a linear location group.

However, sensors in a planar group must have the "DAQ X" direction, displayed on the Horizontal Color CRT Screen Axis (see Fig. A-10).

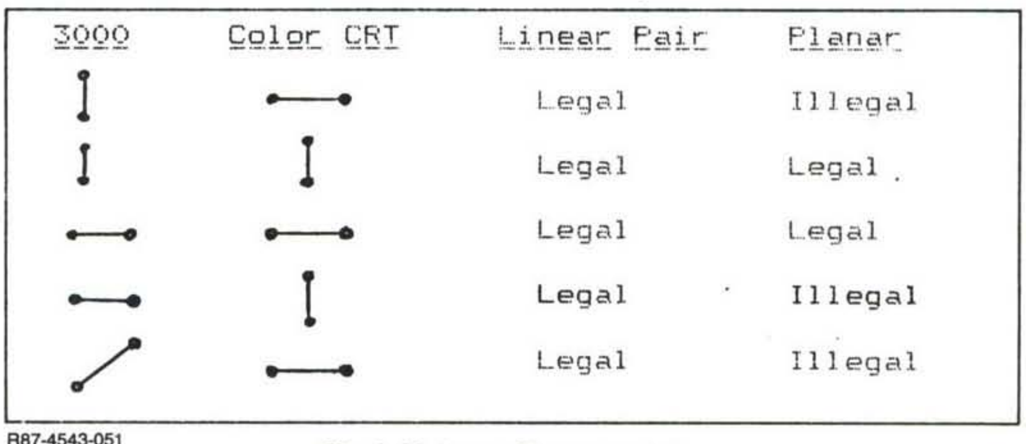

Fig. A-10 Sensor Placement Rules

Replay of files can be done normally, as long as the calibration information sent to the color board corresponds to the calibration used by the GRP/DAQ to do its location calculations.

2.5.2 AEFDSS Specific Modifications

As far as the user can distinguish, the only difference between GRP/DAQ and SPP/DAQ is that when the user is doing data acquisition or replay graphics he can enter [#99 < CRLF >] and the color screen will be copied (#98 will re-draw the screen WITHOUT the location points, BE CAREFUL). The color hard copy should be used judiciously during a test because each copy takes one minute.

APPENDIX A

FILE DEFINITIONS

A.1 PART FILE DESCRIPTION

File consists of a 128 byte header and as many 128 byte records as needed to describe the part.

Header Position	(Bytes) Length	Description
1	1	File type code = 1 for present version
2	1	Version Code (*100)
3	18	Time of Day file was made. Optional (0 terminates T.O.D.)
21	80	80 byte (ASCII character) Part name-number-description (User information : optional)
101	2	Number of items for type 1 file, 1 item type "point" = (2 byte horizontal pos. and 2 byte vertical pos)
103	128	Reserved for future use
Data		
129		Beginning location of first item

Continues until all item records are finished. 0 filled to multiple of 128 bytes.

A.2 SENSOR POSITION FILE

128 byte header followed by sensor positions.

Header Position	(Bytes) Length	Description
1	1	Type byte = 1
2	1	Version byte = 100 (100* version)
3	18	Time of Day (Optional)
21	1	Drive of Part File (# in range 1-16)
22	12	'File name' + '.' + 'EXT' ASCII string for PART descriptor file.
34	2	# Sensor positions included
36-128		Reserved

Data Records		
129		Depends on type byte of file

For type byte = 1, the record per sensor is 6 bytes long.

Sensor Record		
1	1	Sensor #
2	1	0
3	2	Horizontal Position
5	2	Vertical Position

APPENDIX B

DIGITIZER DIP SWITCH SETTINGS*

1) Baud Rate Switch: 9600	(U d d d)	
	(1 2 3 4)	
2) B (Left hand) 8 position switch		(d d d d d d U U)
		(1 2 3 4 5 6 7 8)
3) A (Right hand) 8 position switch		(d U U U d d U U)
		(1 2 3 4 5 6 7 8)

*ALL SWITCHES VIEWED SO THAT NUMBERS ARE RIGHT SIDE UP.
THESE SWITCHES SHOULD NOT BE TOUCHED.

U = Up position, also marked on the switch as "closed".

d = Down position, marked on the switch as "open".